

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-97

Jorge E. Rivera

Technical Memorandum – 2001 – 208589

January 2001

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Kennedy Space Center, Florida*

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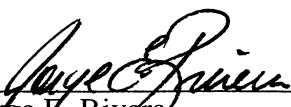
**DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-97**

November 30, 2000

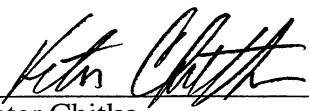
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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.



Photo 1: Launch of Shuttle Mission STS-97

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-97 consisted of OV-105 Endeavour (15th flight), ET-105, and BI-103 SRB's on MLP-1 and Pad 39B. Endeavour was launched at 336:03:06:00.986 UTC (10:06 p.m. local) on 30 November 2000. Landing was at 6:04 p.m. local/eastern time on 11 December 2000.

During the pre tanking debris walkdown at T-8 hours, a de-attached firex bracket was observed on the north side of the OAA white room exterior wall. Due to the FOD potential during OAA retraction a decision was made to retract the OAA and remove the bracket. In addition a U-bolt with missing nut on the vertical riser portion of the firex line was replaced and securely re-attached. An action was taken during the S0007 post test debriefing to review pad inspection and maintenance practices and to implement changes to mitigate FOD production and to enhance FOD detection techniques so as to preclude FOD induced launch countdown delays.

SRB holddown post stud hang-up was observed on HDP#1. The stud appeared to be fully extended before it was released, oscillated back and forth (twang) before falling back into the HDP. No frangible nut debris was seen during liftoff. A piece of shaved aluminum fell from the aft skirt stud hole. As expected, broaching occurred in the holddown stud bore of post #1 consistent with stud hangs-up seen in the post launch film reviews. The Space Shuttle Program continues to investigate SRB holddown post stud hang-ups, reference PRCBD S062159 Action 5-1.

Post landing inspection of Orbiter tiles showed a total of 84 hits, of which 10 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 78 total hits, of which 10 had a major dimension of 1-inch or larger. Approximately 43 damage sites (with three larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. More damage occurred on the right-hand side of the vehicle than on the left-hand, with a typical pattern, some of these hits may be attributed to impacts from ice in the LO2 feedline bellows.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat less than the family average. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites

2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 1400 on 29 November 2000. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

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A. Khodaoust	Boeing	Shuttle Aerodynamics

3.0 LAUNCH

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 29 November 2000. The walkdown of Pad 39B and MLP-1 included the flight elements OV-105 Endeavour (15th flight), ET-105, and BI-103 SRB's. There were no significant SSV discrepancies. Four items as potential debris were entered in OMI S0007 Appendix K for resolution prior to cryoload:

1. Loose and peeling RTV on MLP 0-level north side of LH2 TSM
2. Pin at N/W egress platform on MLP 0-level needed securing
3. A piece of rope on water pipe at MLP 0-level LH SRB inboard water support
4. Pin at N/E egress platform on MLP 0-level was missing

In addition, IPR 097V-0110 was taken against Pad facility, during the pre tanking debris walkdown at T-8 hours, a de-attached firex bracket was observed on the north side of the OAA white room exterior wall. Due to the FOD potential during OAA retraction a decision was made to retract the OAA and remove the bracket using a Condor Highlift. In addition a U-bolt with missing nut on the vertical riser portion of the firex line was replaced and securely re-attached. This task delayed ET cryoloading by approximately two hours. The IPR was closed and a facility PR (PV-6-369353) was generated with MRB approval to use-as-is for this flight only.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 30 November 2000 from 1643 to 1923 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There were also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact but three covers (R4U, F3D, F1L) were discolored. Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements.

The Final Inspection Team observed no condensate on the LO2 tank acreage. Surface temperatures ranged from 44 to 46 degrees Fahrenheit. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. A total of two cracks in the intertank stringer valley TPS were observed (-Y/-Z side and -Y/+Z side). Neither cracks exhibited ice, frost, nor offset. Therefore, the cracks were acceptable for flight per the NSTS-08303 criteria. Ice and frost accumulations on the GUCP were typical.

Light condensate was present on the LH2 tank acreage. Surface temperatures ranged on the upper 40 degrees Fahrenheit. Small frost line was noted on the aft side of the -Y bipod ramp at the ramp to acreage interface. There were no acreage TPS anomalies.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A .5-inches in length and .125 inches wide stress relief crack was observed in the -Y vertical strut TPS with no offset. This condition has been accepted for flight on previous vehicles.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were present on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals. A grass fire was observed just south of the LH2 flare stacks. The fire appears to have emanated from nesting material or other debris that may have been ejected from the LH2 flare stack during topping. Part of it could have then blown off the stack onto the ground from the northerly winds that were there at the time. Several steps have already been taken to preclude another grass fire near the Pad. Further more, some additional long-term actions are being reviewed to reduce the opportunity for grass fires in the area during ET LH2 loading at either Pad.

3.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no ice zone".

STS-97 was launched at 336:03:06:00.986 UTC (10:06 p.m. local) on 30 November 2000.

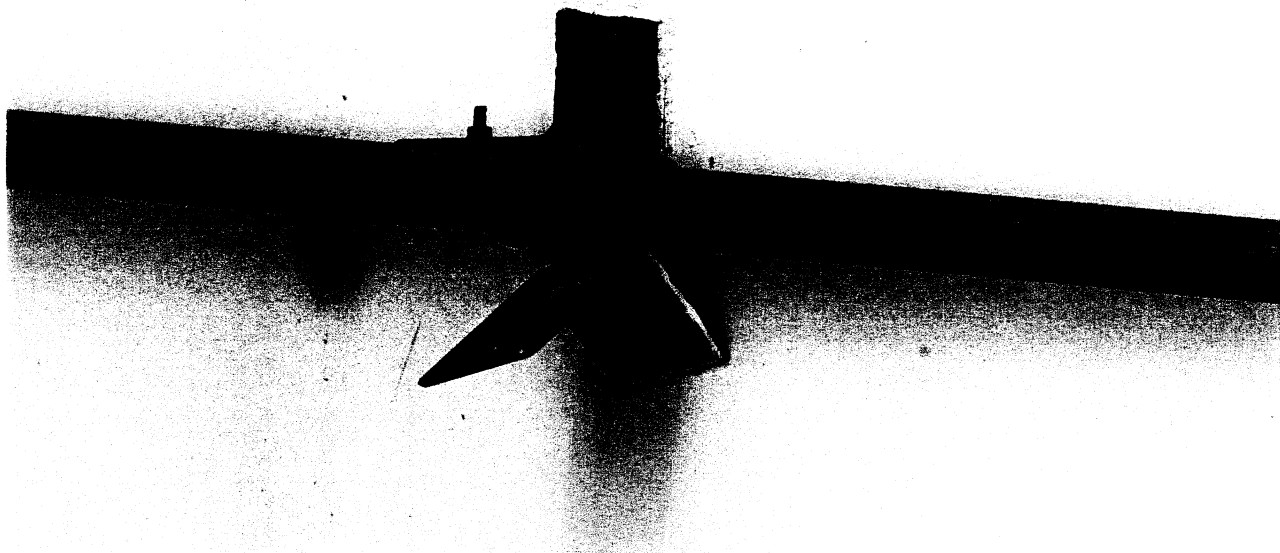
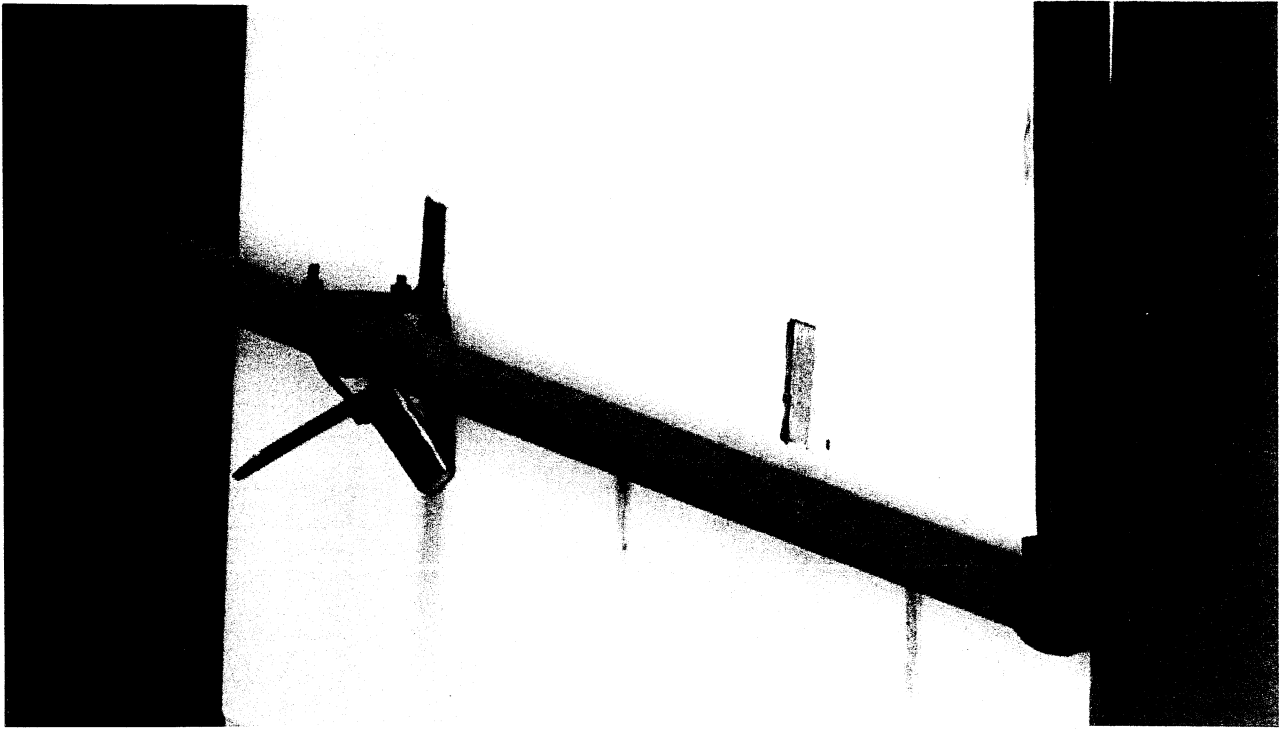


Photo 2: De-attached firex bracket on the OAA

During the pre tanking debris walkdown at T-8 hours, a de-attached firex bracket was observed on the north side of the OAA white room exterior wall. The bracket was removed using a Condor Highlift.

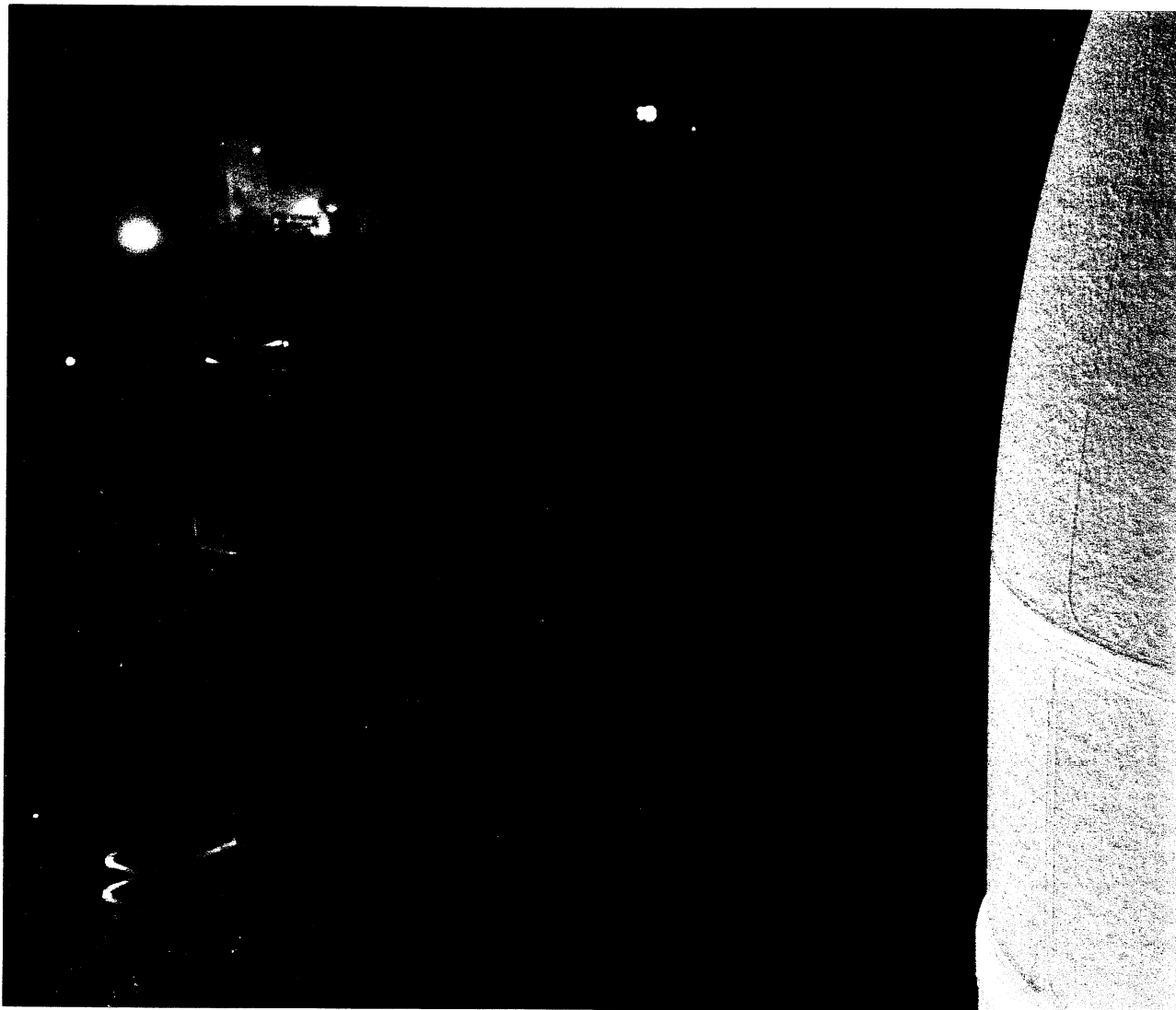


Photo 3: Grass fire near the LH2 flare stacks.

A grass fire was observed just south of the LH2 flare stacks. The fire appears to have emanated from nesting material or other debris that may have been ejected from the LH2 flare stack during topping

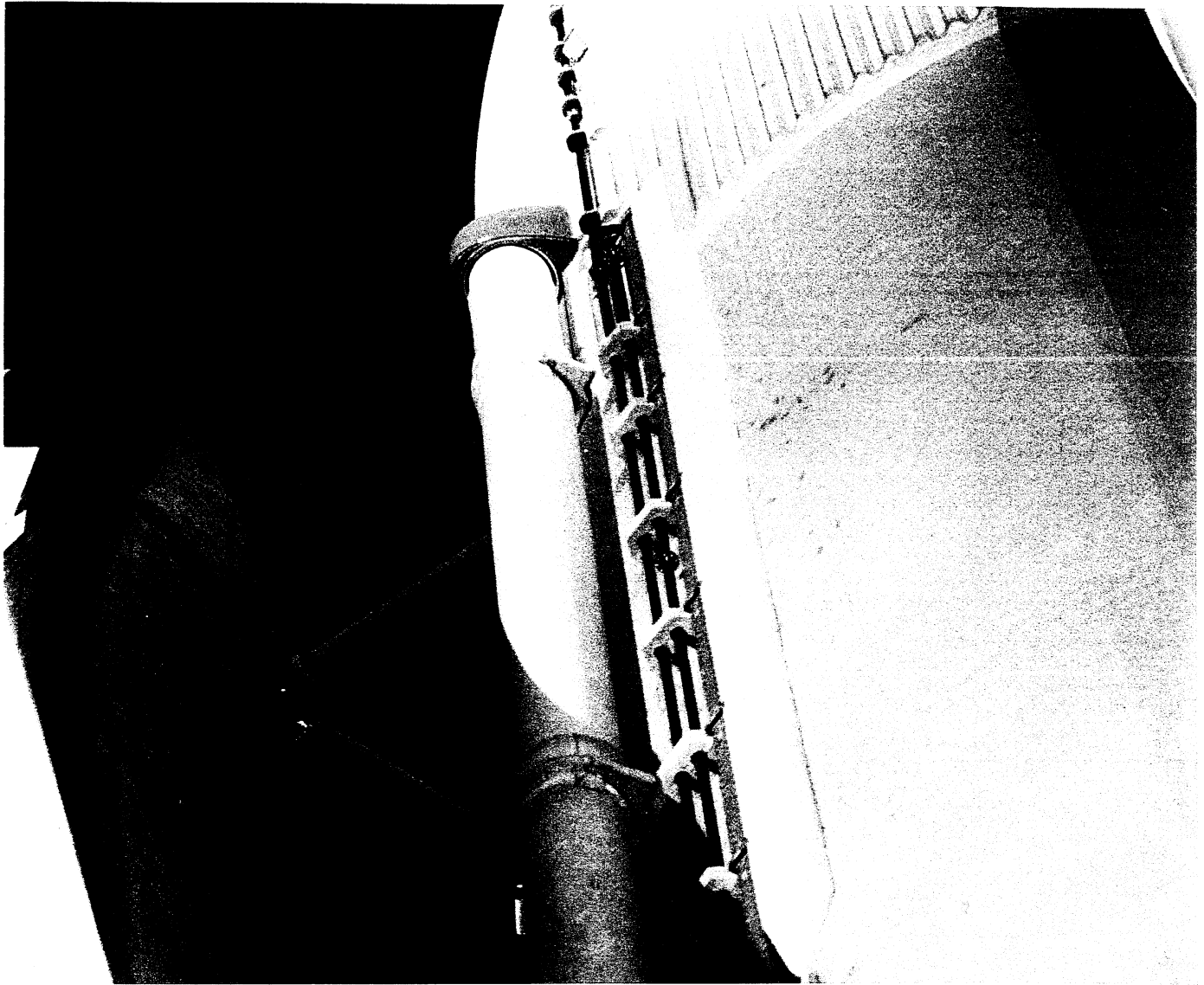


Photo 4: LH2 Tank Acreage

Light condensate was present on the LH2 tank acreage. Surface temperature ranged on the upper 40 degrees Fahrenheit. There were no acreage TPS anomalies.

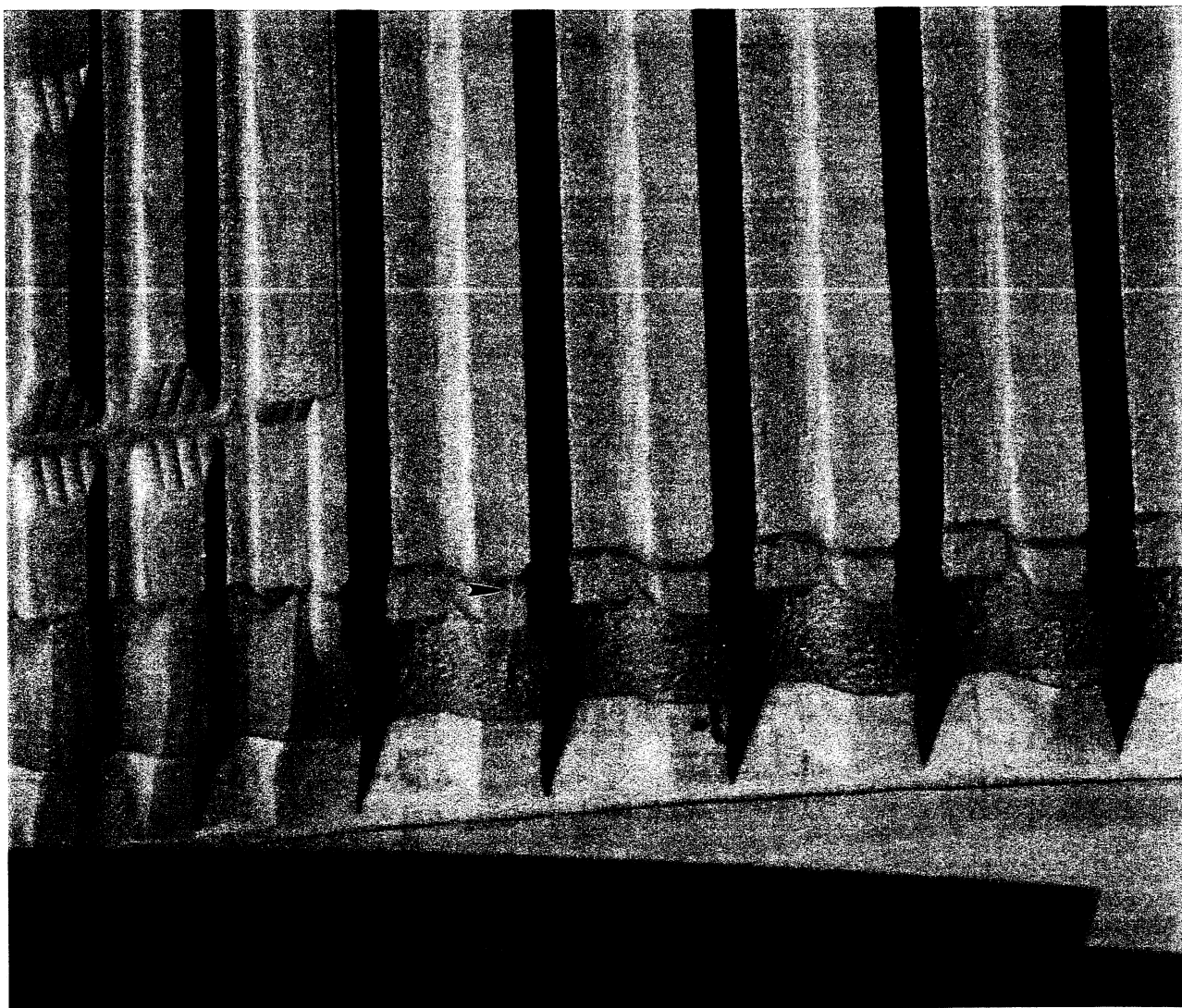


Photo 5: Cracks in Intertank Stringer Valleys

No significant anomalies were present in the intertank TPS. Two small stringer valley TPS cracks were observed (-Y/-Z side and -Y/+Z side).

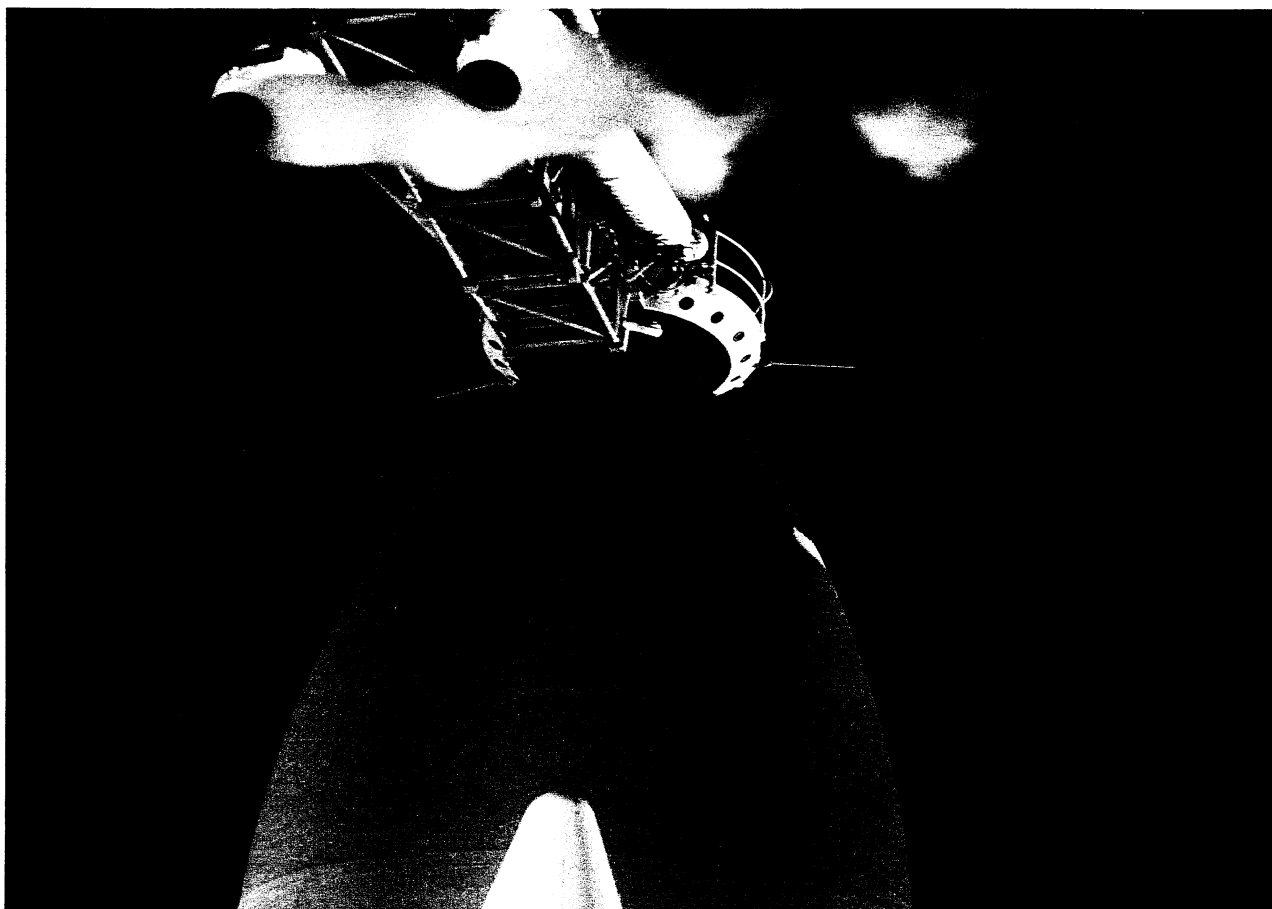


Photo 6: ET LO2 Tank forward

The Final Inspection Team observed no condensate on the LO2 tank acreage. Surface temperatures ranged from 44 to 46 degrees Fahrenheit. There were no TPS anomalies.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP-1, Pad B FSS and RSS was conducted on 01 December 2000 from Launch + 2 to 4 hours. No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach indicated that a hang-up had occurred. No signs of stud hang-ups were detected in the visual inspection of the four south posts. Erosion was typical for the north posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the bonnets were closed properly. The MLP deck was in generally good shape.

The GH2 vent line latched in the second of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage.

The OAA appeared to be intact with no evidence of plume impingement. A thorough inspection of the firex pipe and attachment showed no indication of damage or anomaly, especially in the area of the removed loose bracket that was accomplished during pre-launch countdown activities.

All slidewire baskets were secured with no evidence of damage.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings included:

- No significant damage was noted in the flame trenches.
- No flight debris was found on the Pad apron.
- No unusual debris items were found on the FSS

Overall, damage to the pad appeared to be minimal. Minimal debris was noted on pad apron and FSS.

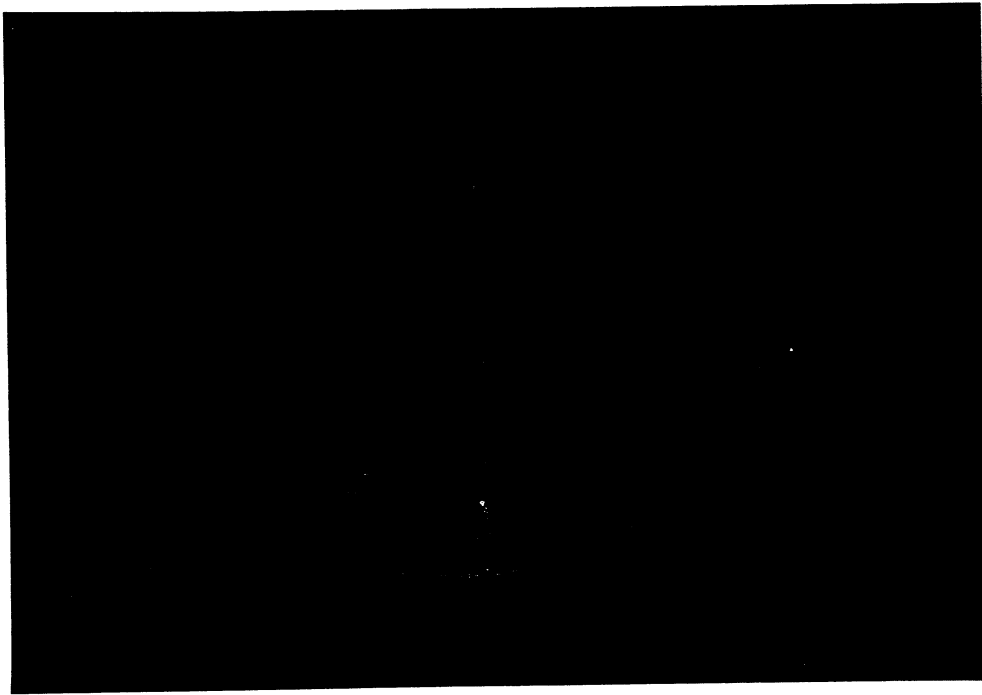
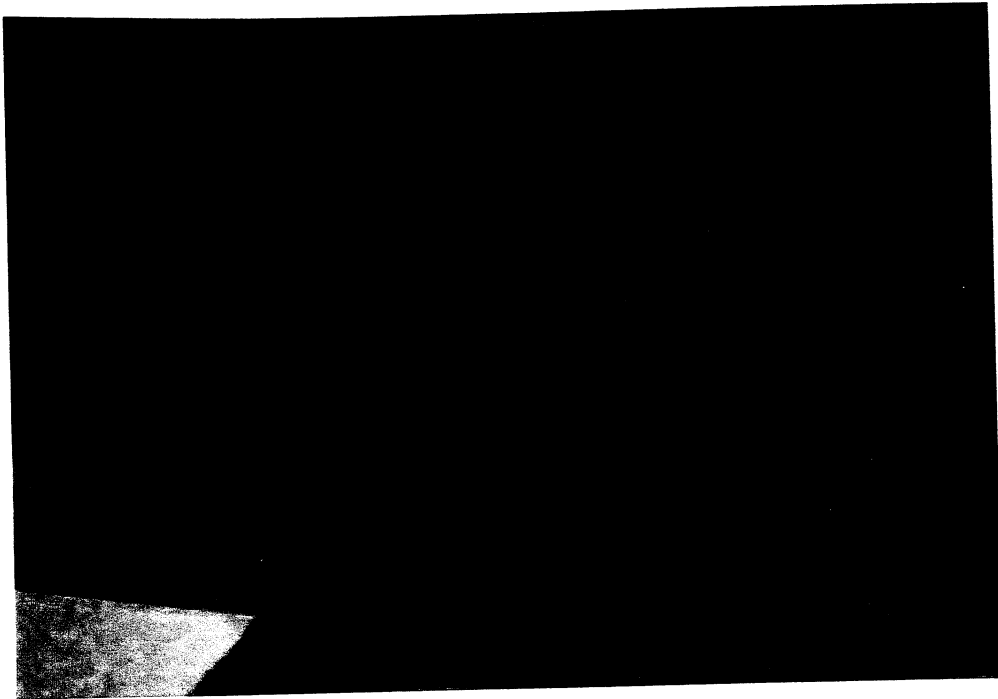


Photo 7: Aft Skirt GN2 Purge Lines

Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded.

5.0 FILM REVIEW

Anomalies observed in the Film Review were reported to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 81 films and videos, which included twenty-seven 16mm films, sixteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

New cameras mounted in the GOX Vent Hood clearly showed no ice or frost formation on the ET louvers during cryogenic loading and stable replenish. Frost, but no ice, formed when the purge was terminated and the hood lifted at T - 2:30.

SSME ignition appeared normal (OTV 051, 070). A considerable amount of free burning hydrogen was visible in the orbiter base heat shield area and rising to the vertical stabilizer before dissipating. Three streaks/flashes occurred in the SSME #1 exhaust plume during startup (E-2, -19, -62).

Periodic APU exhaust gas (aprox. 5 feet in length) at the right hand side base of the vertical stabilizer, (note observations from films E-52, E-63, E-76, E-220, E-222 and E-77).

Body flap motion appears to be "more than usual" (film E-223).

A piece of debris was observed from SRB aft skirt visible left side of the vehicle (outside plume); late ascent after roll maneuvering (film E220). The object could not be resolved/identified.

Small pieces of tile surface coating material were shaken loose by SSME ignition acoustics/vibration from seven places on the base heat shield near SSME #3, seven places on the base heat shield near SSME #2, two places on the right OMS heat shield, one place on the right APCS pod, and one place on the left APCS pod (E-17, -18, -19, -20, -31).

Numerous pieces of ice from the ET/ORB umbilicals shook loose and contacted umbilical sill tiles and ET cable tray TPS, but no damage was detected (OTV 009, 063).

A small piece of ice from the SSME nozzle fell and contacted the body flap. Size, mass, and velocity were insufficient to cause tile damage (E-5).

LH2 and LO2 T-0 umbilical disconnect was normal (OTV 049, 050, E36).

GUCP disconnect from the ET was nominal (E-33).

Normal pieces of SRB throat plug were ejected from the exhaust holes and flame trench at T-0 (E-63).

Less than usual facility debris particles were observed after vehicle clears the tower. (E-40)

Vapors emanating from ET aft dome were caused by TPS outgassing rather than condensate vaporizing (E-52).

A trail of vapor was seen at the mid-portion of the aft edge of the rudder speed brake during ascent (E222). This area was inspected after landing no anomaly was found.

Light colored streaks/ashes occurred in the SSME exhaust plume during startup, typical of previous missions (E-2).

More than usual GVA hood motion was observed on camera E-62 after the vehicle had cleared the tower. Replacement of hood jackscrew assembly was required per launch load OMRSD inspection criteria. (Ref. PR's U78-0001-00-002-0546 and -0547)

Slag (molten aluminum oxide) particles fell out of SRB plume at tailoff and after separation (E205).

Numerous pieces of debris were observed near the ET LH2 (OTV ET-207 and E-52) aft dome manhole cover closeout during the roll maneuvering. The particles could not be resolved/identified. A possibility is that these debris particles are butcher paper material originated from the LH2 umbilical side fire detection system or perhaps pieces of umbilical baggies.

Four to five pieces of tile surface coating material or tile repair material areas fell from lower surface black tiles shortly after liftoff due to acoustic vibration (E-17). This is typical of previous missions.

A SRB holddown post stud hang-up was observed on HDP #1(E-9). The stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post. A piece of shaved aluminum from the bore fell with the stud (broaching was visible during the SRB Post Flight Assessment).

Both SRB GN2 purge lines separated cleanly from the aft skirt and were in nominal condition until lost from view by smoke (E-8, -13)

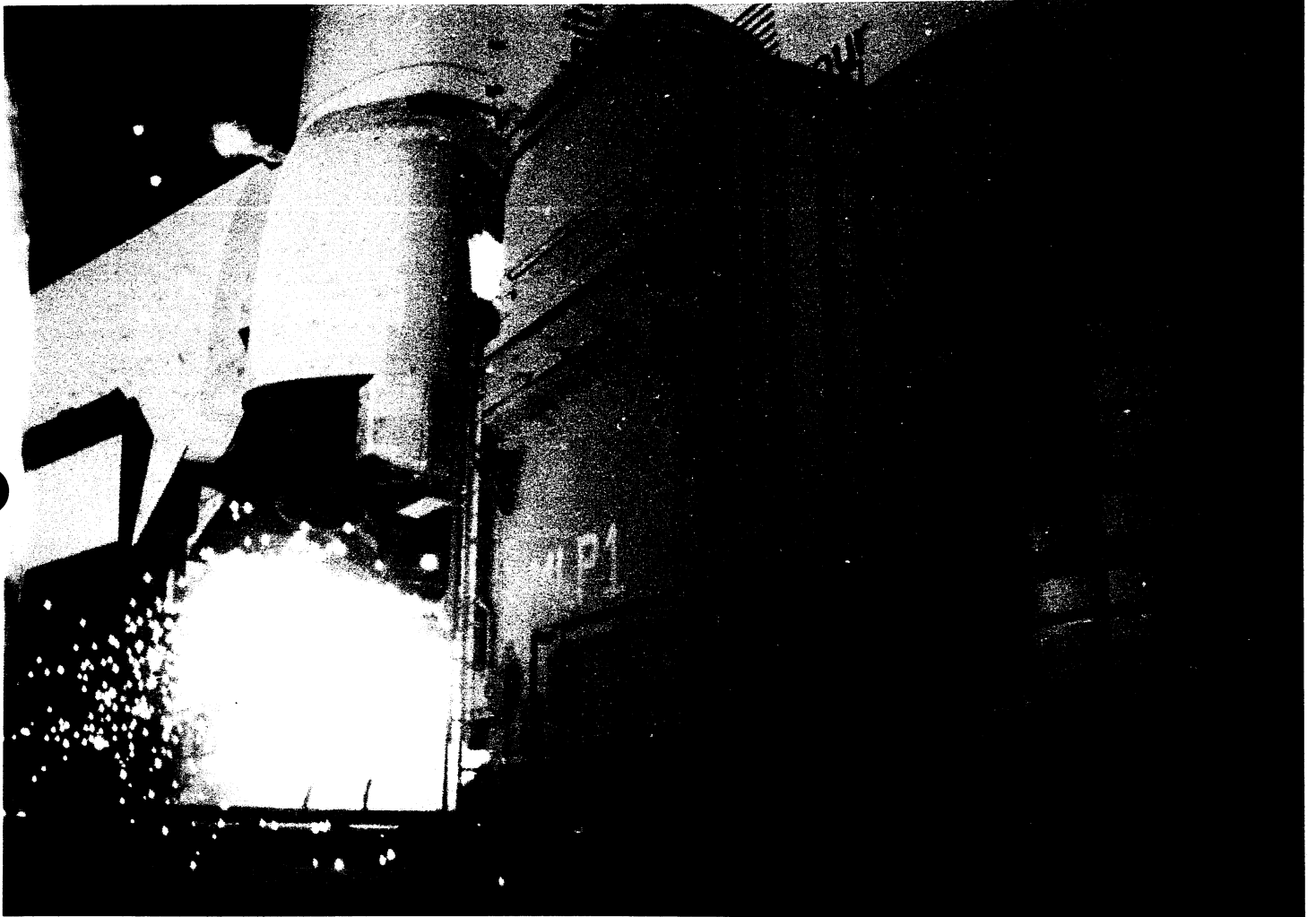


Photo 8: Pulsating Flames from Orbiter APU

Pulsating flame were observed on +Z APU vent exhaust (aprox. 5 feet in length) at the right hand side base of the vertical stabilizer.

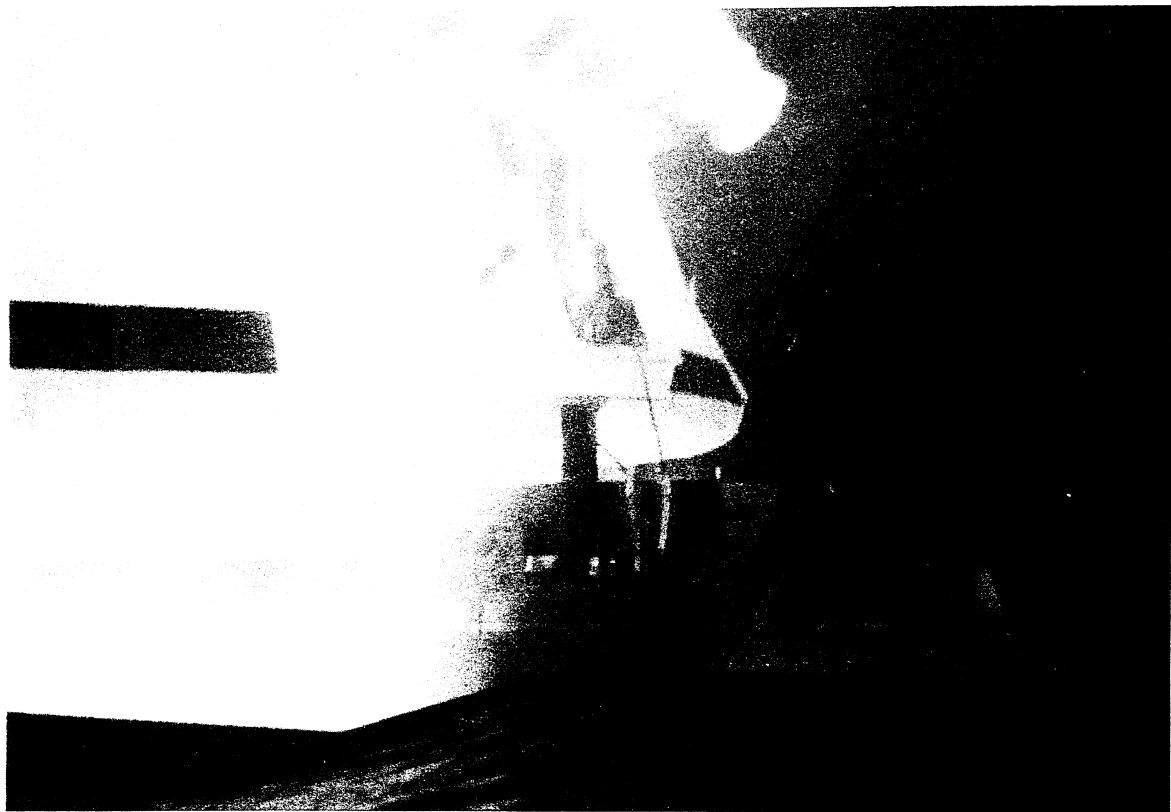


Photo 9: SRB Stud Hang-up

A SRB holddown post stud hang-up was observed on HDP #1(E-9). The stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post.

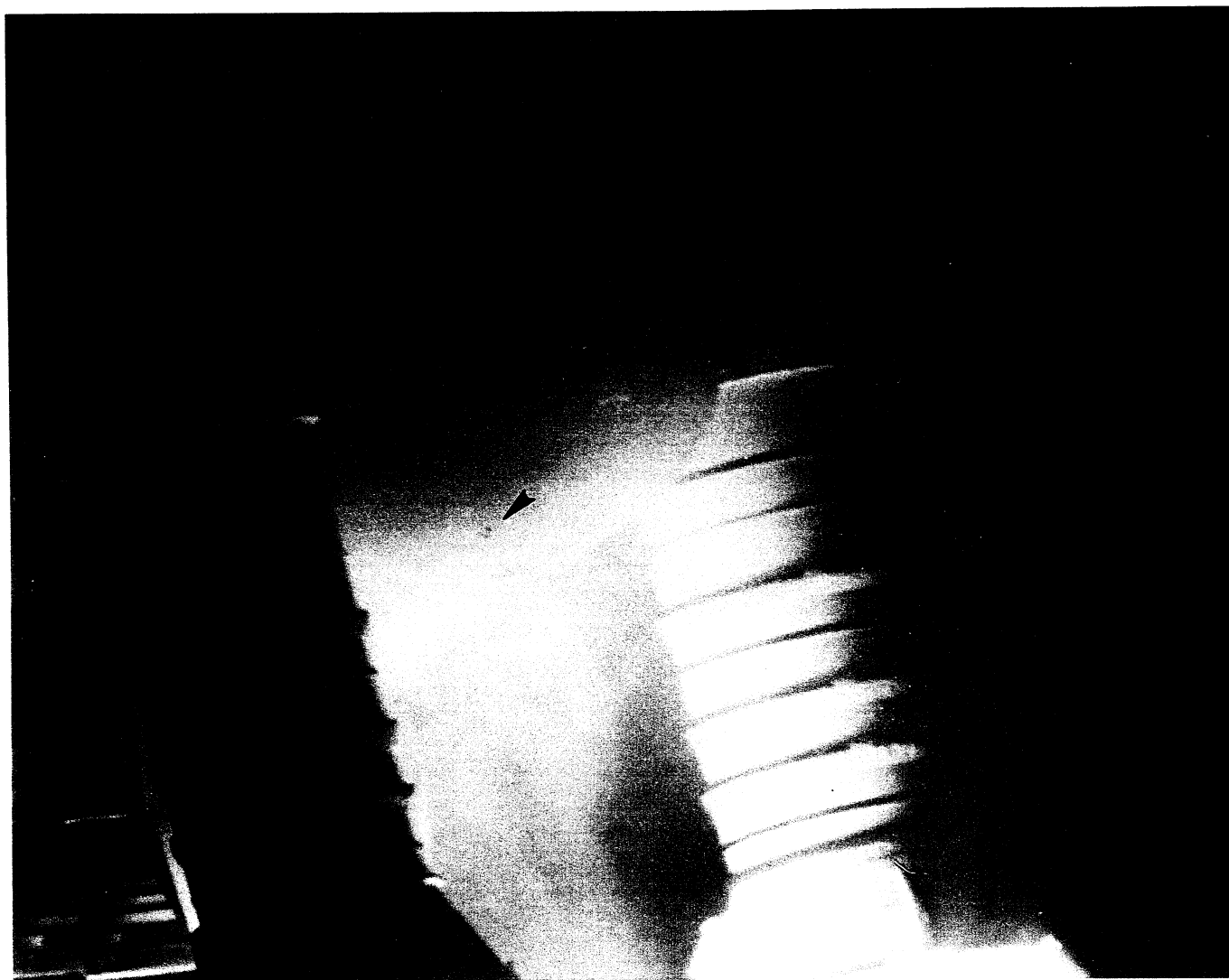


Photo 10: Dark Debris near ET Aft Dome during Roll Maneuver

Numerous pieces of debris were observed near the ET LH2 (OTV ET-207 and E-52) aft dome manhole cover closeout during the roll maneuvering. The particles could not be resolved/identified. A possibility is that these debris particles are butcher paper material originated from the LH2 umbilical side fire detection system or perhaps pieces of umbilical baggies.



Photo 11: Astronaut Handheld Camera View of the External Tank

Image from the Astronaut Handheld Camera provided limited data. No anomalous condition were noticed

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

As expected, no Solid Rocket Booster or External Tank separation photography was acquired on STS-97. This flight provided no Umbilical Well films for review and the night landing resulted in extremely limited data for review. There were only 11 frames of 35mm Crew handheld camera film and these were with the tank at least 4km away. The two 16mm cameras in the LO2 ET/ORB umbilical were disabled prior to launch because of an electrical short problem.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 17 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly. The right MLG tires contacted the runway first.

Drag chute deployment appeared normal. No anomalies were detected from touchdown through rollout. No unusual tile damage was visible in the films.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-103 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 04 December 2000. Generally, both boosters were in excellent condition.

As expected, broaching occurred in the holddown stud bores of posts #1, consistent with stud hang-up seen in the post launch film reviews. Broached area was generally on the +Z side of the bore.

The RSRB +Z RSS antenna has damage in the form of missing material to one corner.

The TPS on both frustums exhibited no debonds/unbonds.

All eight BSM aero heat shield covers had fully opened and locked.

The forward skirts exhibited no debonds or missing TPS. The LSRB +Z RSS antenna had some small pieces of SLA material missing (may be caused by ablation). The LSRB +Z antenna base plate had one phenolic layer delaminated.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds observed.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation close-outs and GEI cork runs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally.

In summary both SRB's were found in good condition regarding debris assessment.

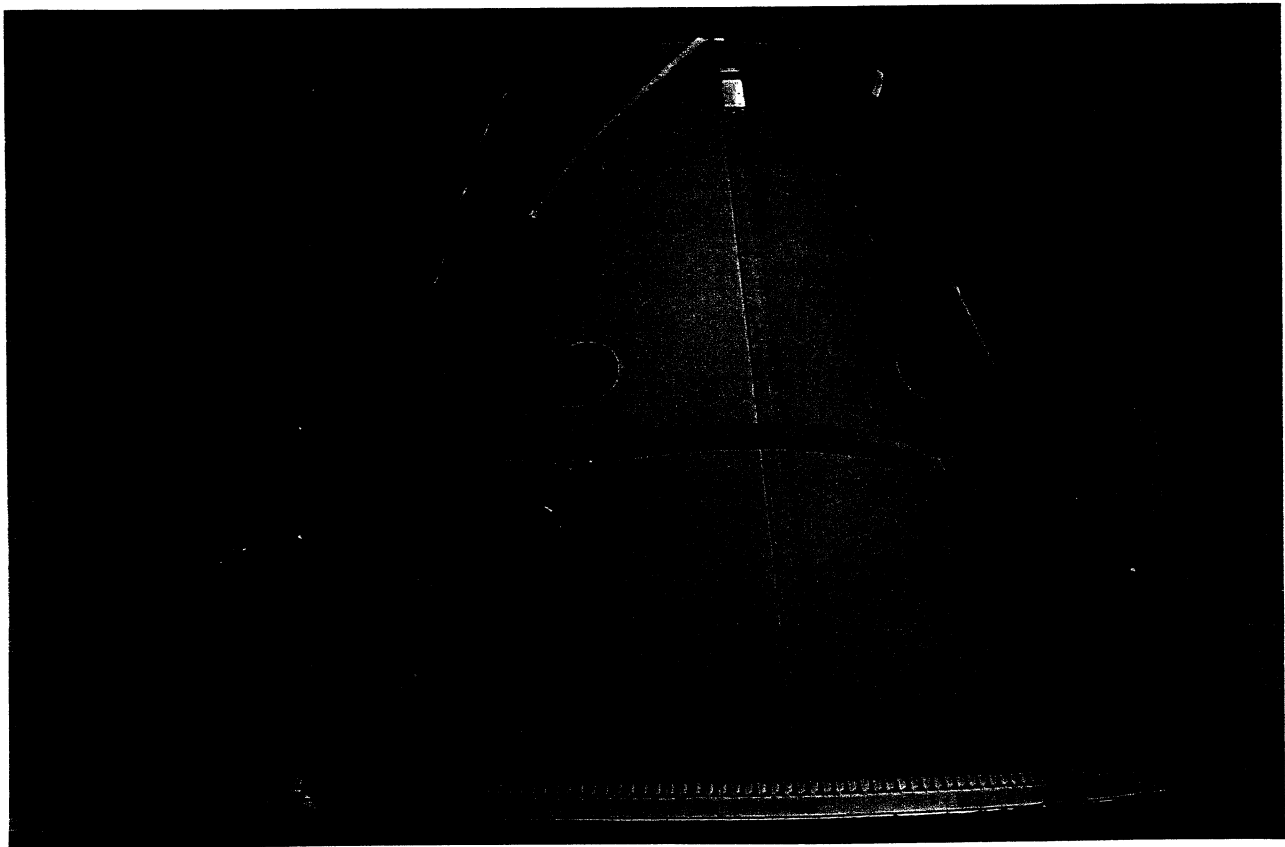
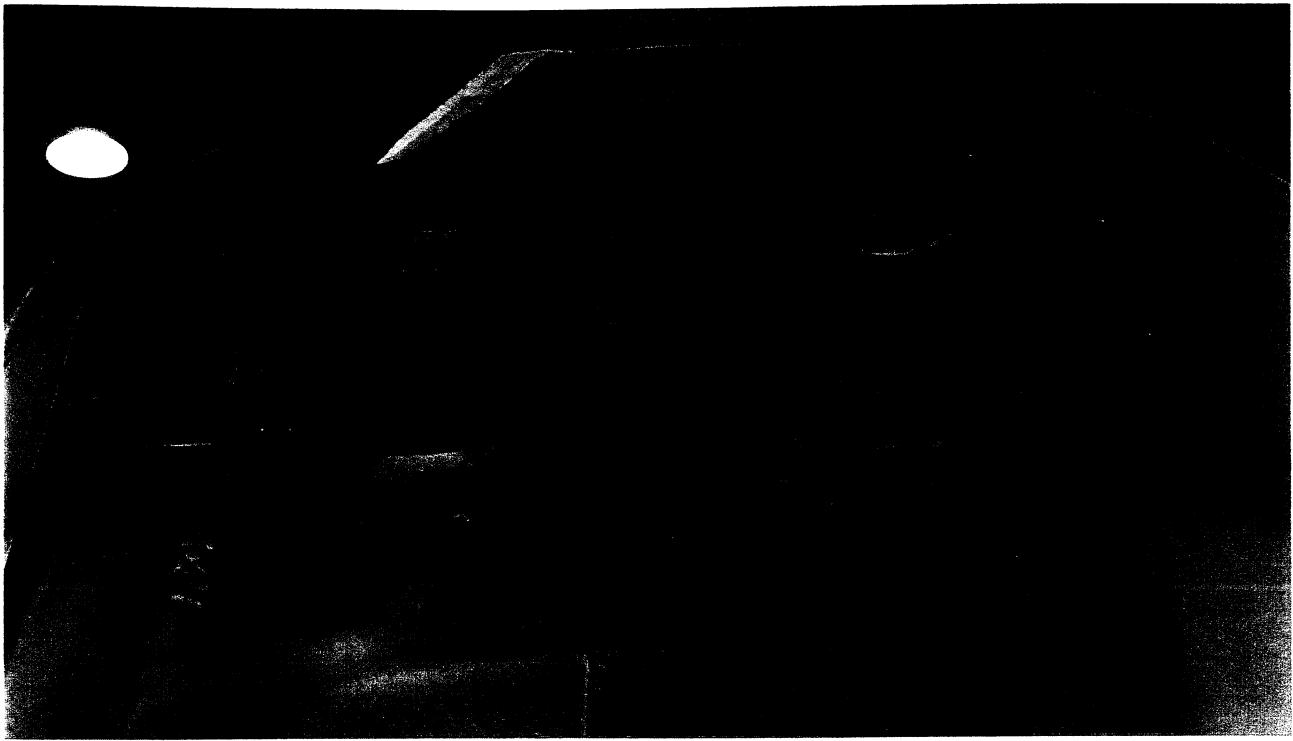


Photo 12: Frustum Post Flight Condition

The frustums exhibited no debonds/unbonds or missing TPS.
All eight BSM aero heat shield covers had locked in the typical opened position.

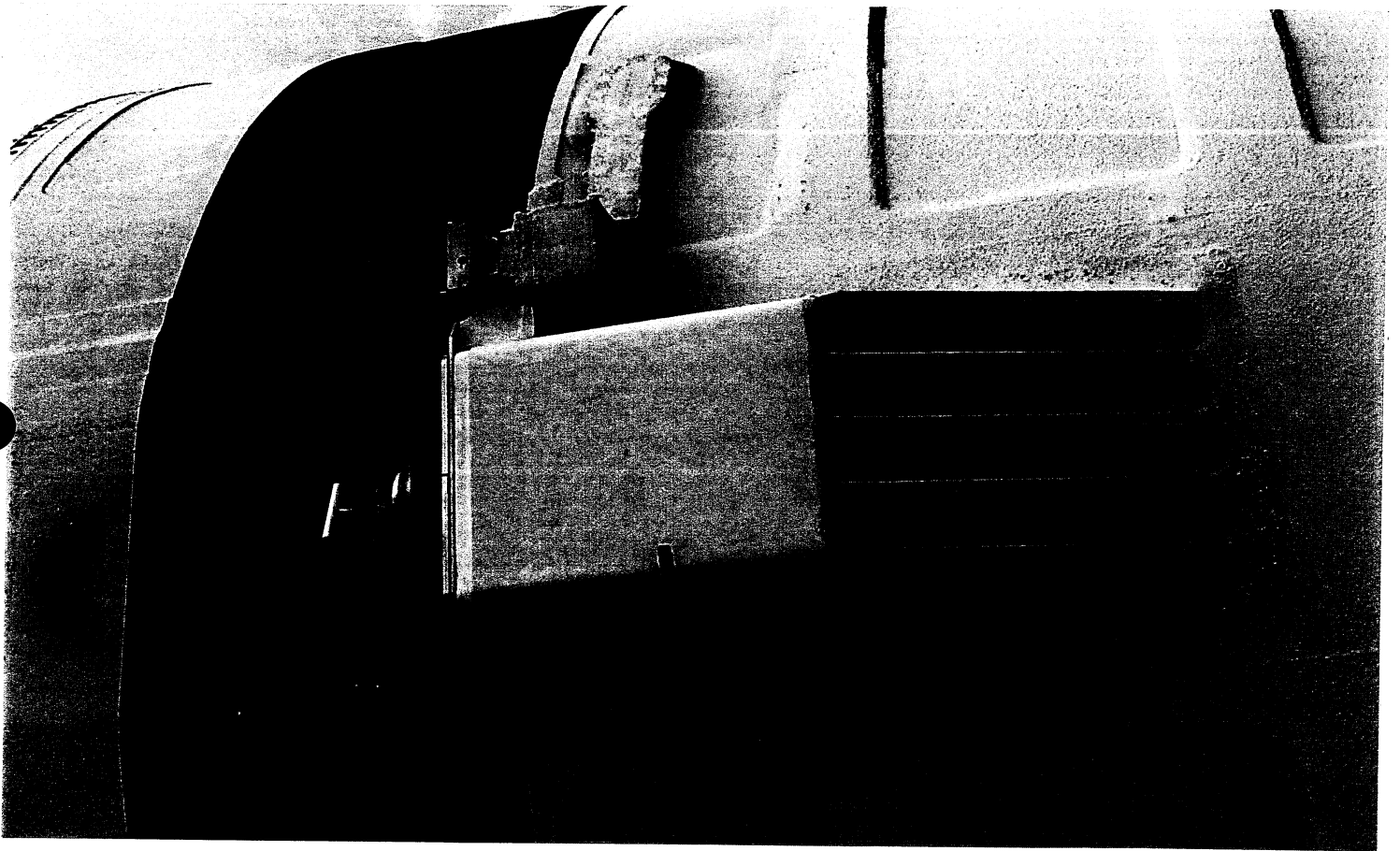


Photo 13: Forward Skirt Post Flight Condition
The forward skirts exhibited no debonds or missing TPS.

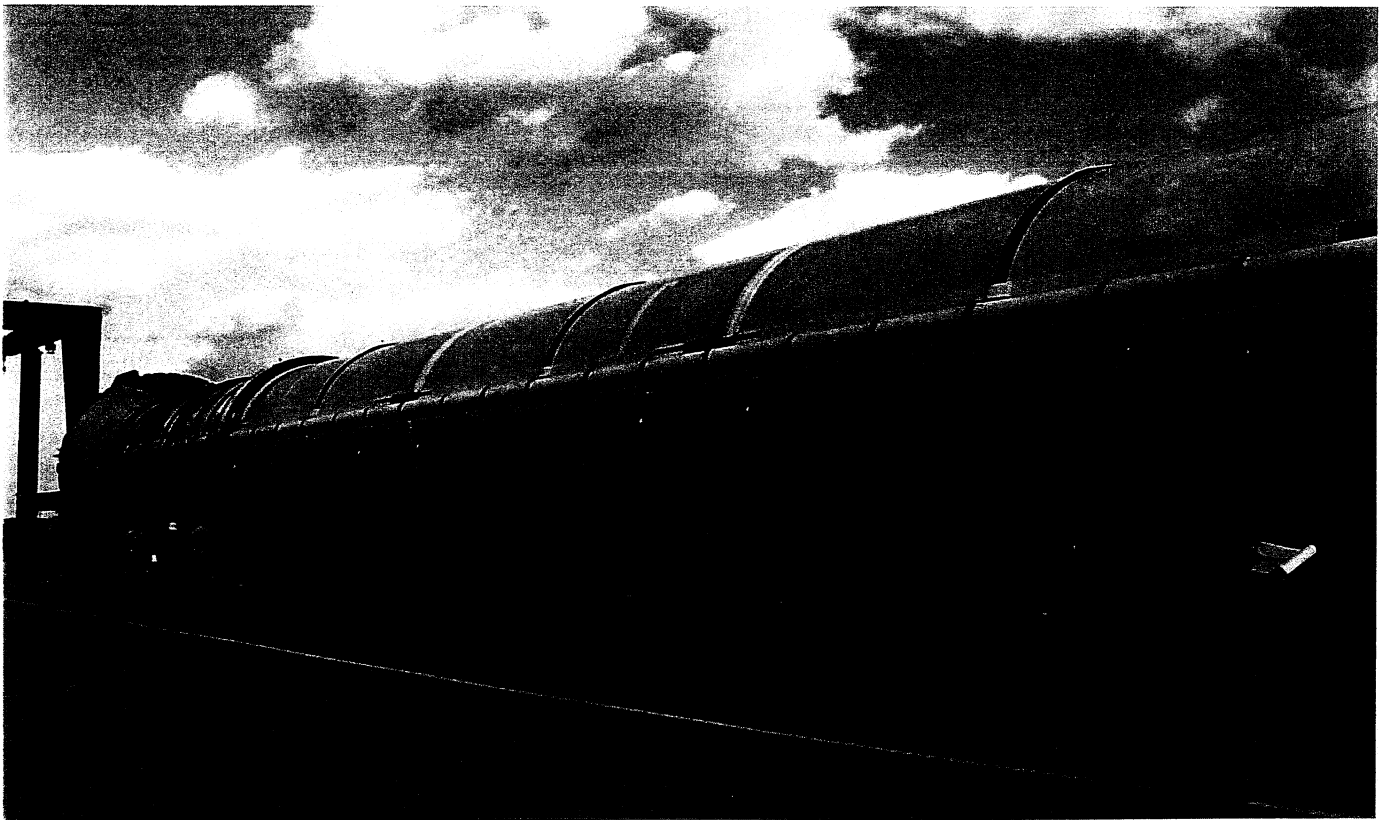


Photo 14: SRB Post Flight Condition

Both SRB's were found in good condition regarding debris assessment

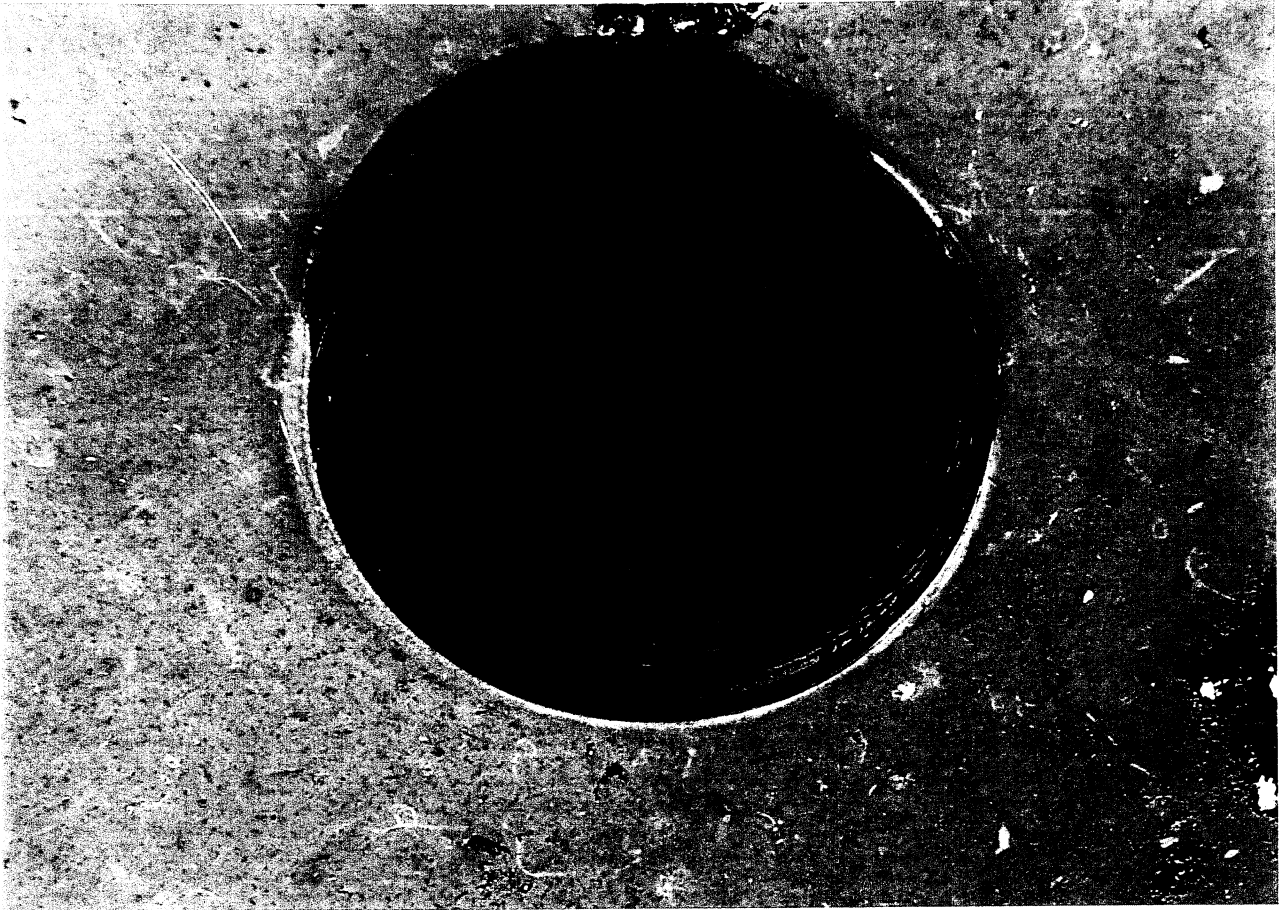


Photo 15: Holddown Post Broaching

There was evidence of a stud hang-up on this launch. Broaching occurred in the holddown stud bore of post #1, consistent with stud hang-up seen in the post launch film reviews. Broached area was generally on the +Z side of the bore.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 6:04 p.m. local/eastern time landing on 11 December 2000, a post landing inspection of OV-105 Endeavour was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 84 hits of which 10 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shields attributed to SSME vibration/acoustics and exhaust plume recirculation.

The following table lists the STS-097 Orbiter damage hits by area:

	<u>HITS > 1-inch</u>	<u>TOTAL HITS</u>
Lower Surface	10	78
Upper Surface	0	0
Window Area	0	4
Right Side	0	0
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	0	2
TOTALS	10	84

The orbiter lower surface sustained 78 total hits, of which 10 had a major dimension of 1-inch or larger. Approximately 43 damage sites (with three larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. More damage occurred on the right-hand side of the vehicle than on the left-hand, with a typical pattern, some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

The largest lower surface tile damage site, located on the center line immediately forward of the main landing gear, measured 3-inches long by 1-inches wide by 0.5-inches deep, spans two tiles. The cause of this damage site has not been determined yet.

Some damage sites around the LO2 ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

The landing gear tires were reported to be in good condition. There was no ply under cutting on the main landing gear tires.

One protruding AMES gap filler was found on the L/H Main Landing Gear Door approximately 0.300" tapering to 0.150".

ET/Orbiter separation devices EO-1 and EO-3 functioned normally. The EO-2 pyro debris shutters were not fully seated and it appears to be obstructed by ordnance fragment. A 0.06-inch diameter by 1.5-inch long piece of wire with red insulation was found on the ET door LH2 side. This piece of wire was positively identified as a fragment of EO-2 ordnance firing cable. A piece (3.5" x 1.5" x .75") of umbilical closeout foam (pyro can closeout) was adhered to the umbilical plate near the LO2 disconnect. No ordnance fragments were found on the runway beneath the umbilicals. The EO-2 and EO-3 fitting retainer springs appeared to be in nominal configuration. No debris was found beneath the umbilicals.

Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in excellent condition.

No unusual tile damage occurred on the leading edges of the OMS pods. Only two small hits were noted on the leading edge of the left OMS pod. There was no debris hit noted on right OMS pod.

No tile damage sites were observed on vertical stabilizer leading edge.

Damage sites on the window perimeter tiles were less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate.

The post-landing walkdown of Runway 15 was performed immediately after landing. All components of the drag chute were recovered and appeared to have functioned normally. Three FRSI plugs were found on the runway, FRSI plugs have been found on previous missions and are not considered an anomaly.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were well within established family (reference Figures 3, 4 and 5).

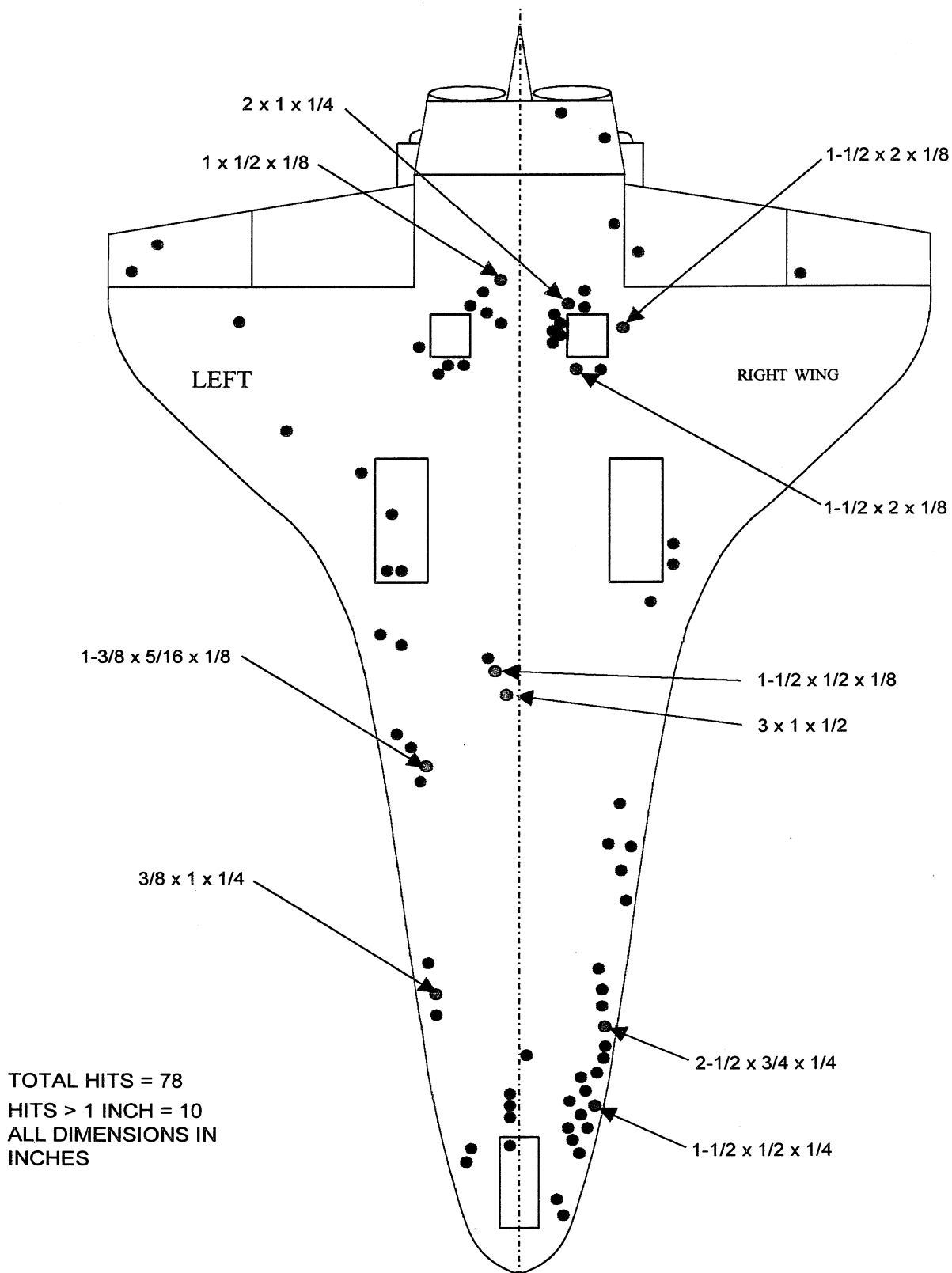


Figure 1: Orbiter Lower Surface Debris Damage Map

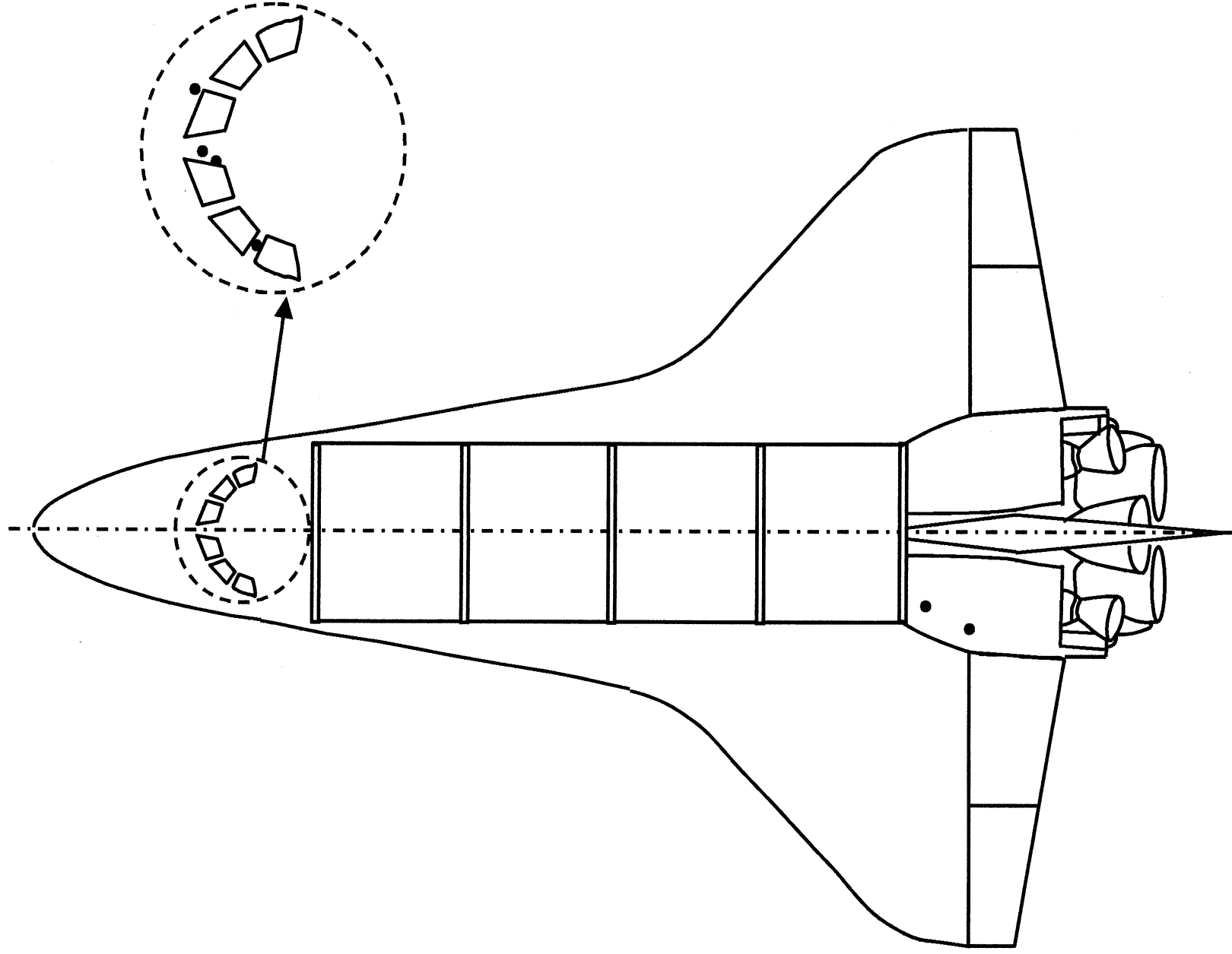


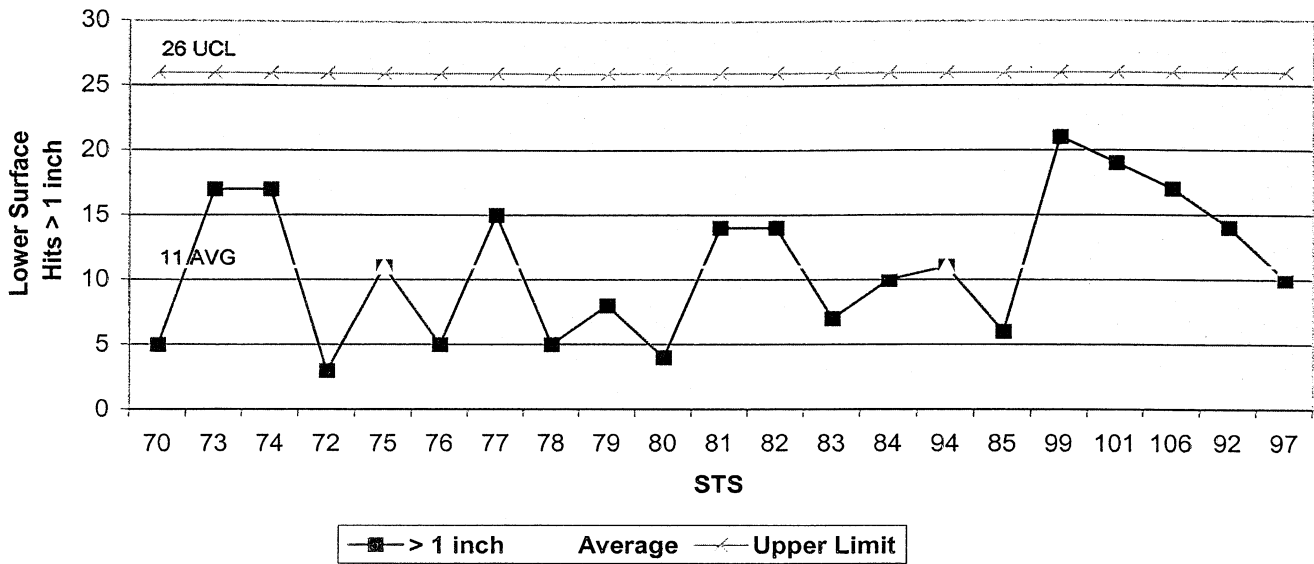
Figure 2: Orbiter Upper Surface Debris Damage Map

STS NUMBER	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
STS-99	21	75	25	88
STS-101	19	70	27	113
STS-106	17	73	17	105
STS-92	14	86	24	127
AVERAGE	11.7	62.3	16.5	103.9
SIGMA	5.9	33.5	6.4	29.7
STS-97	10	78	10	84

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 3: Orbiter Post Flight Debris Damage Summary

Orbiter Post Flight Debris Damage Lower Surface Hits >1 inch



Orbiter Post Flight Debris Damage Lower Surface Total Hits

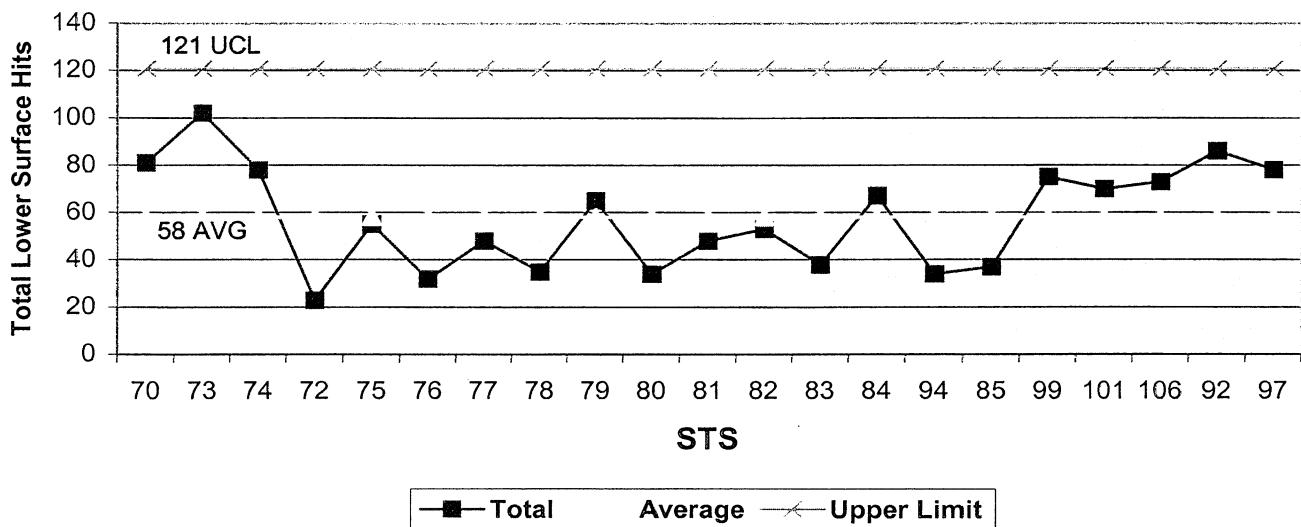


Figure 4: Control Limits for Lower Surface Hits

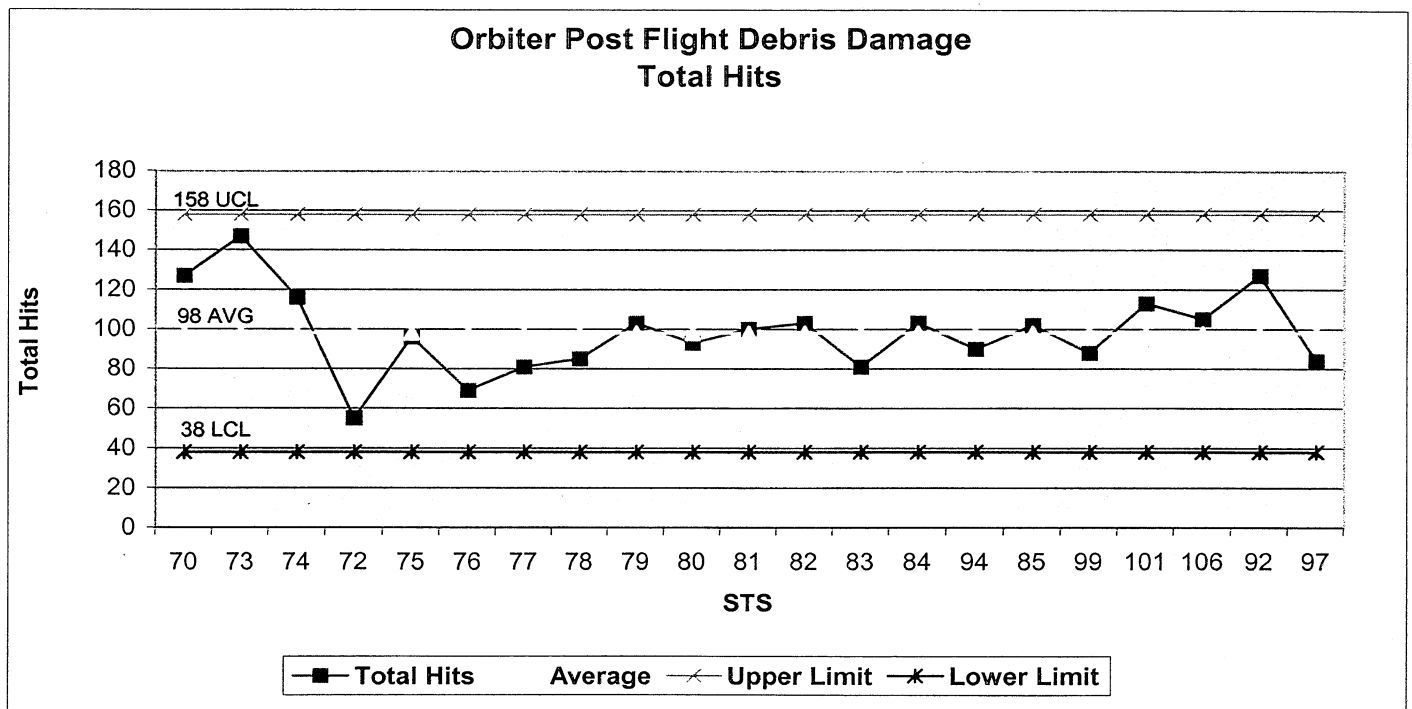
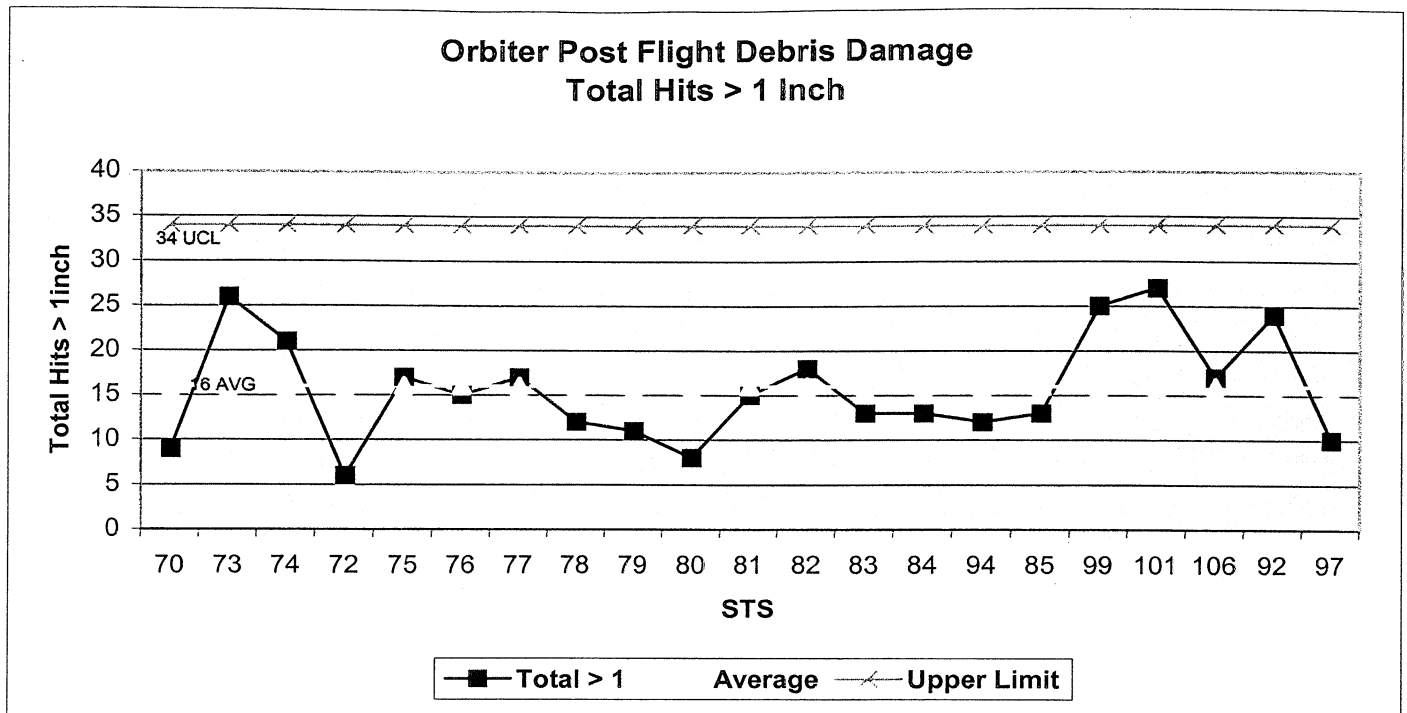


Figure 5: Control Limits for Total Hits

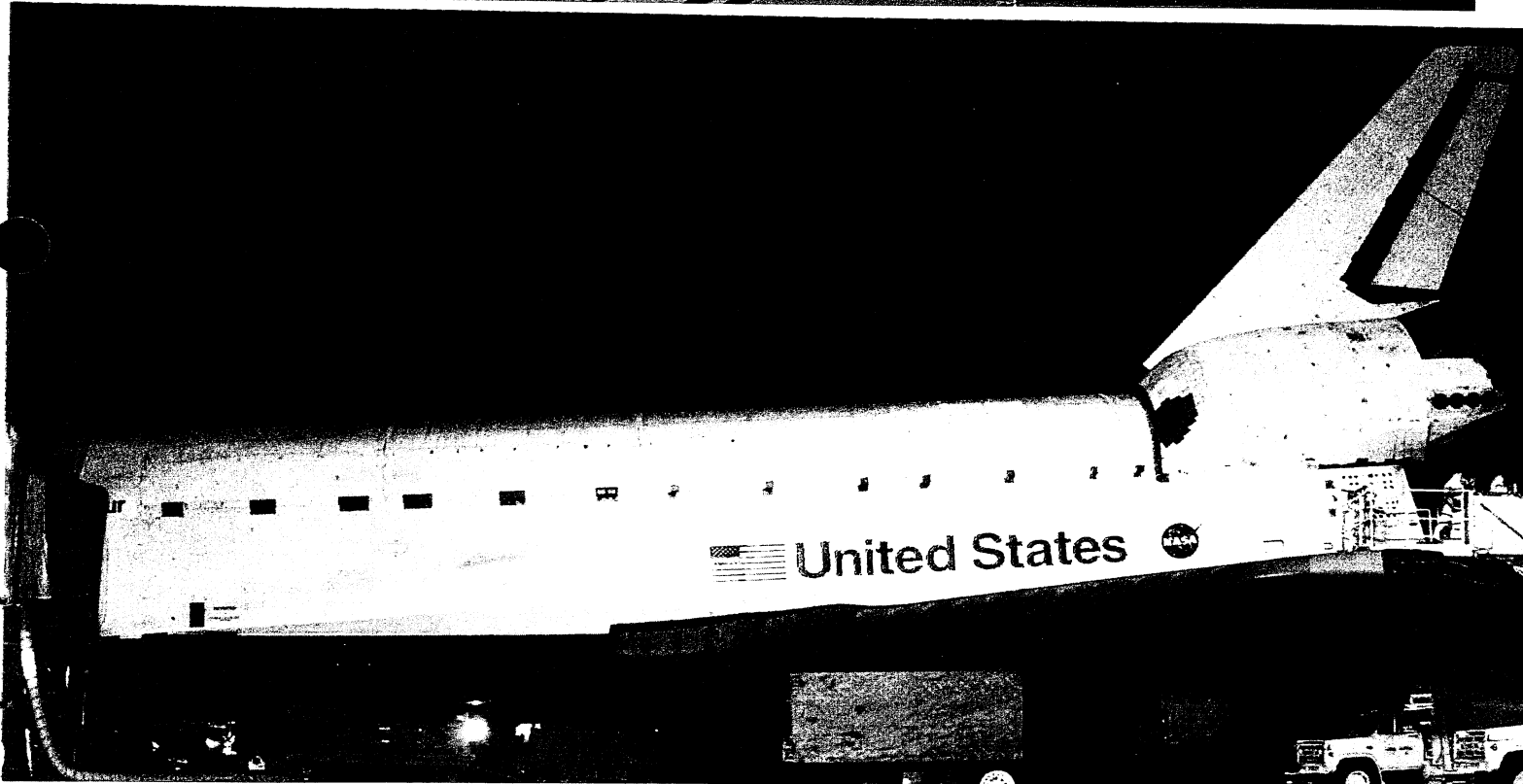


Photo 16: Overall View of Orbiter Sides

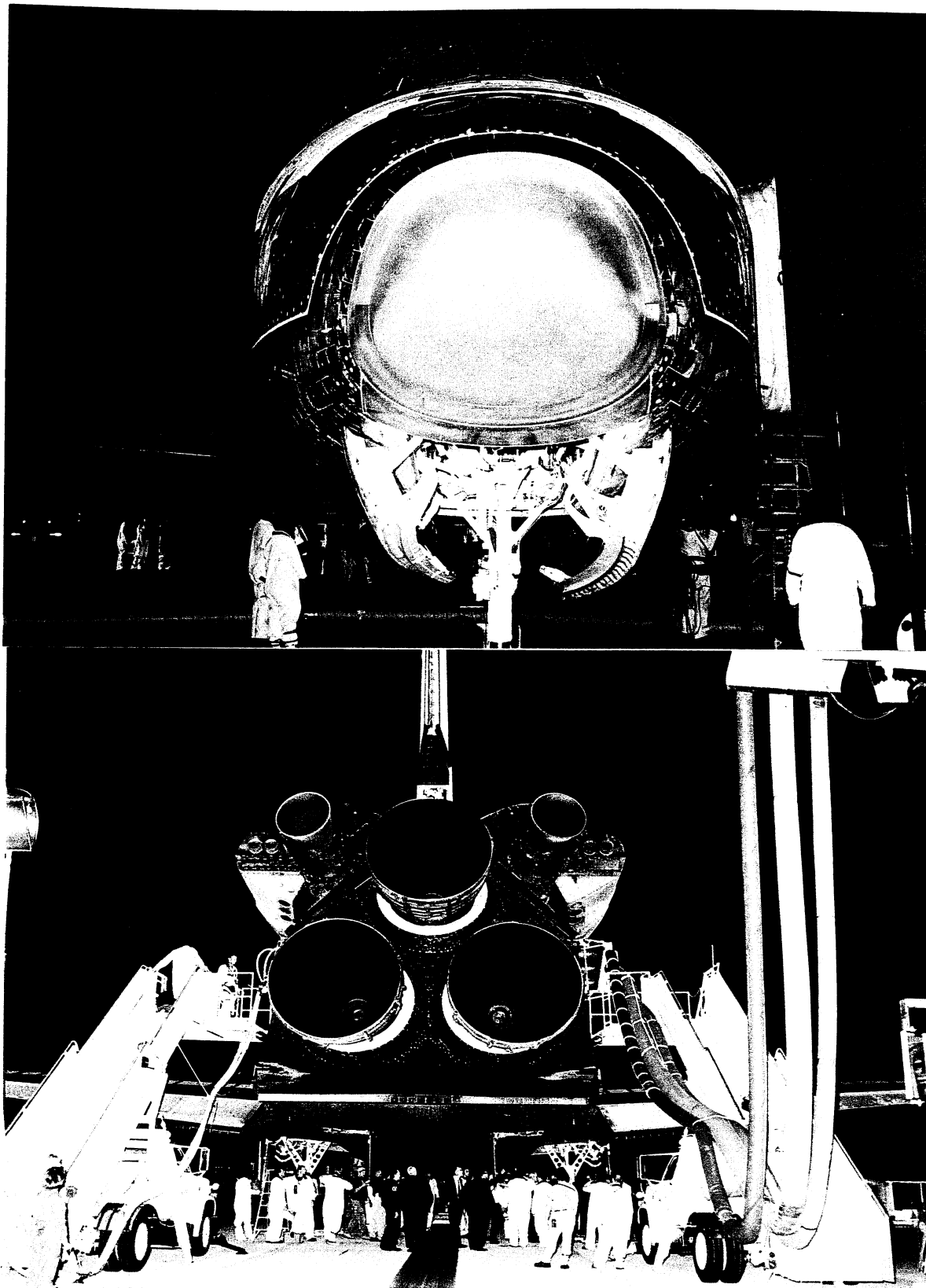


Photo 17: Windows and Base Heat Shield

Damage sites on the window perimeter tiles were less than usual in quantity and size. Also Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in excellent condition.

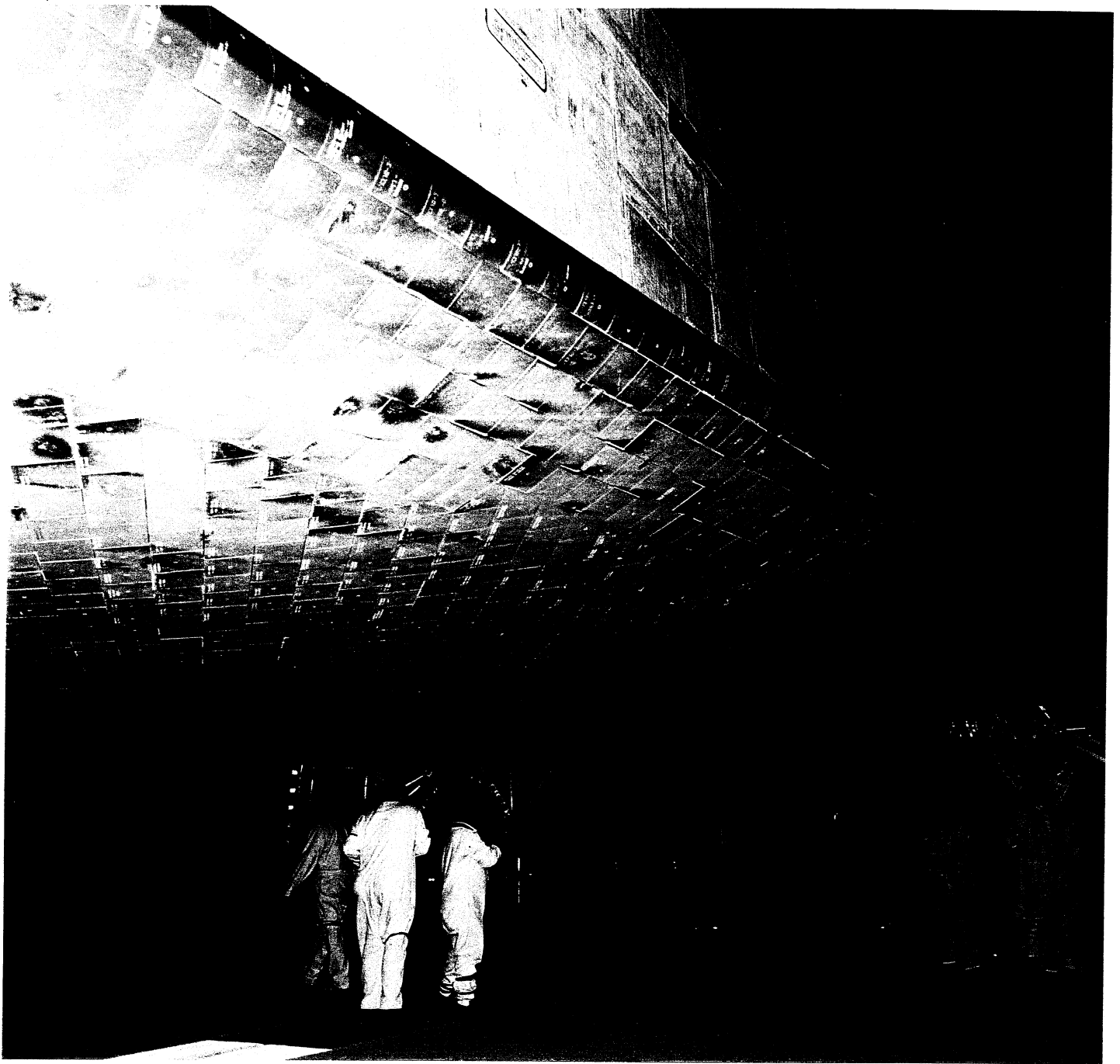


Photo 18: Damage to Lower Surface Tiles .

The orbiter lower surface sustained only 78 total hits. Both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were well within established family

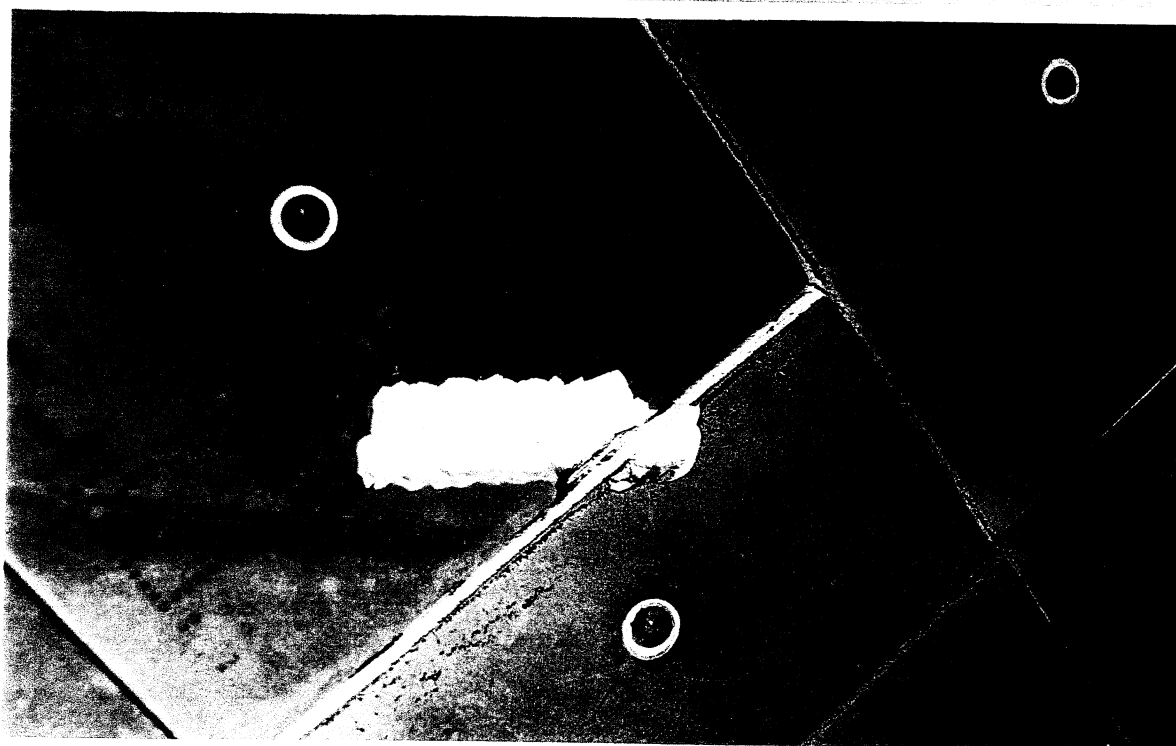


Photo 19: Damage to Lower Surface Tiles

Top photo shows a protruding AMES gap filler found on the L/H Door approximately 0.300" tapering to 0.150". Bottom photo shows the largest lower surface tile damage site. This damage site was located on the centerline immediately forward of the main landing gear, measured 3-inches long by 1-inches wide by 0.5-inches deep, and spans two tiles.

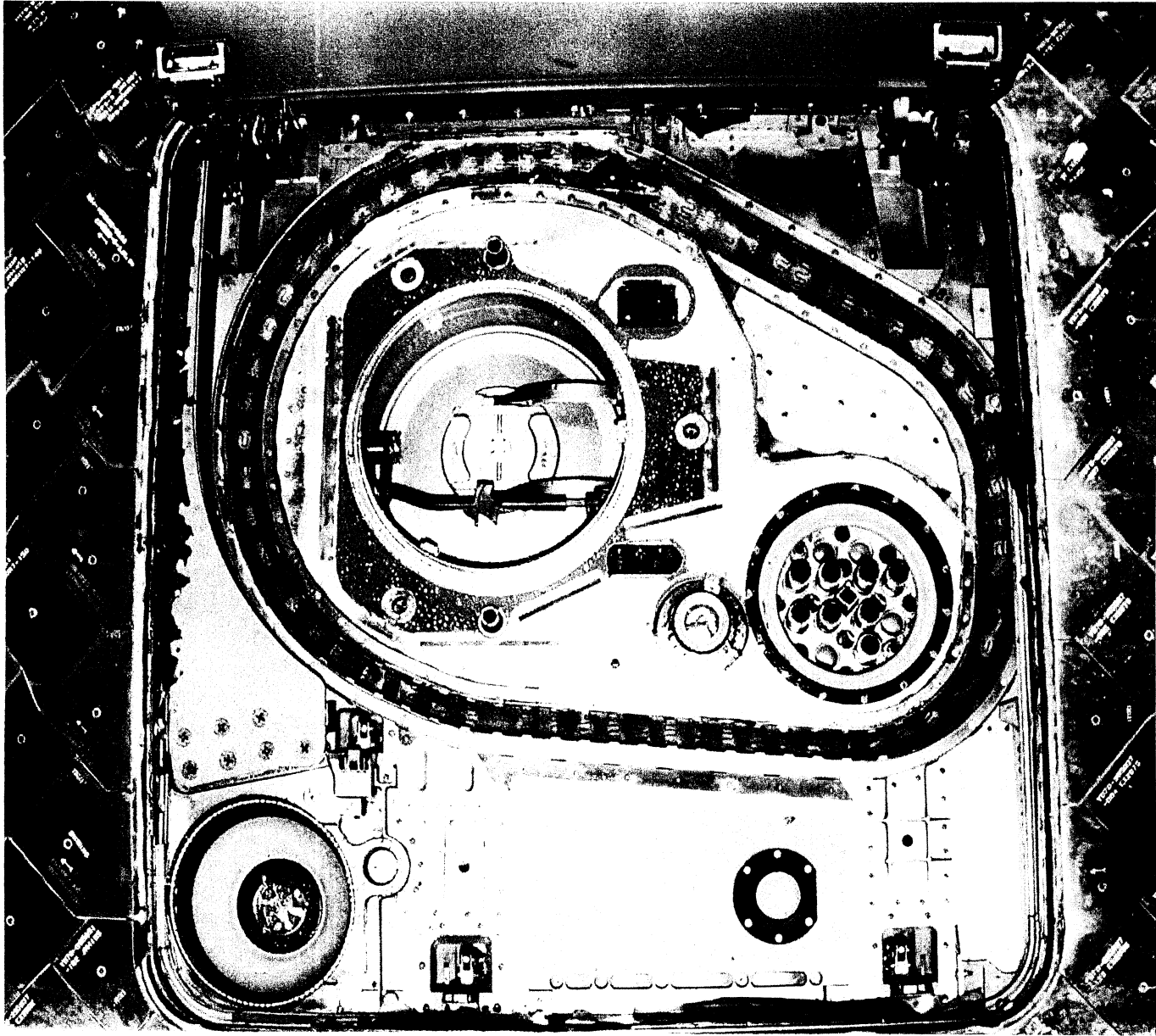


Photo 20: LO2 ET/ORB Umbilical

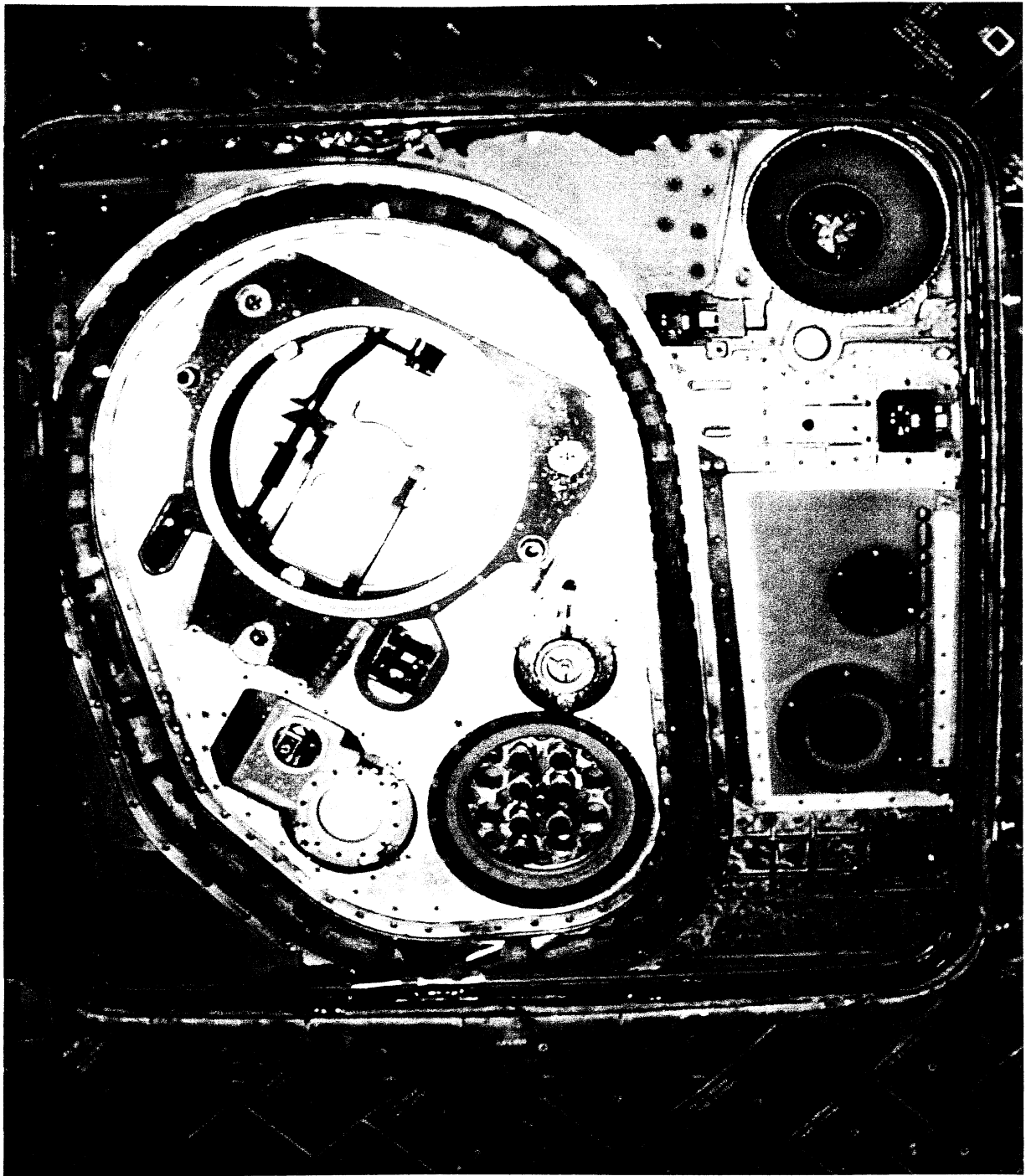


Photo 21: LH2 ET/ORB Umbilical

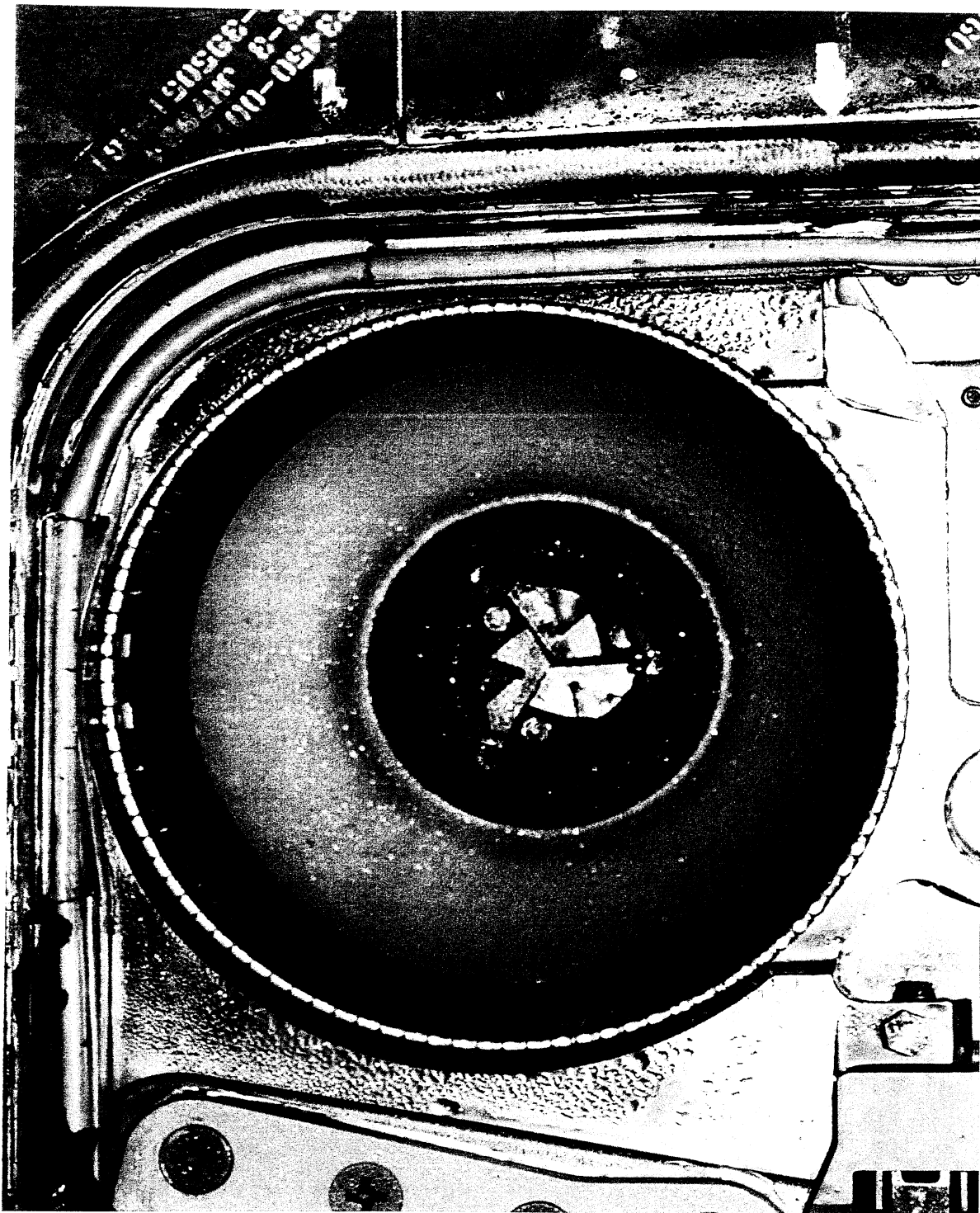


Photo 22: EO-2 Pyro Debris Shutters

EO-2 pyro debris shutters were not fully seated. It was found to be obstructed by ordnance fragment.

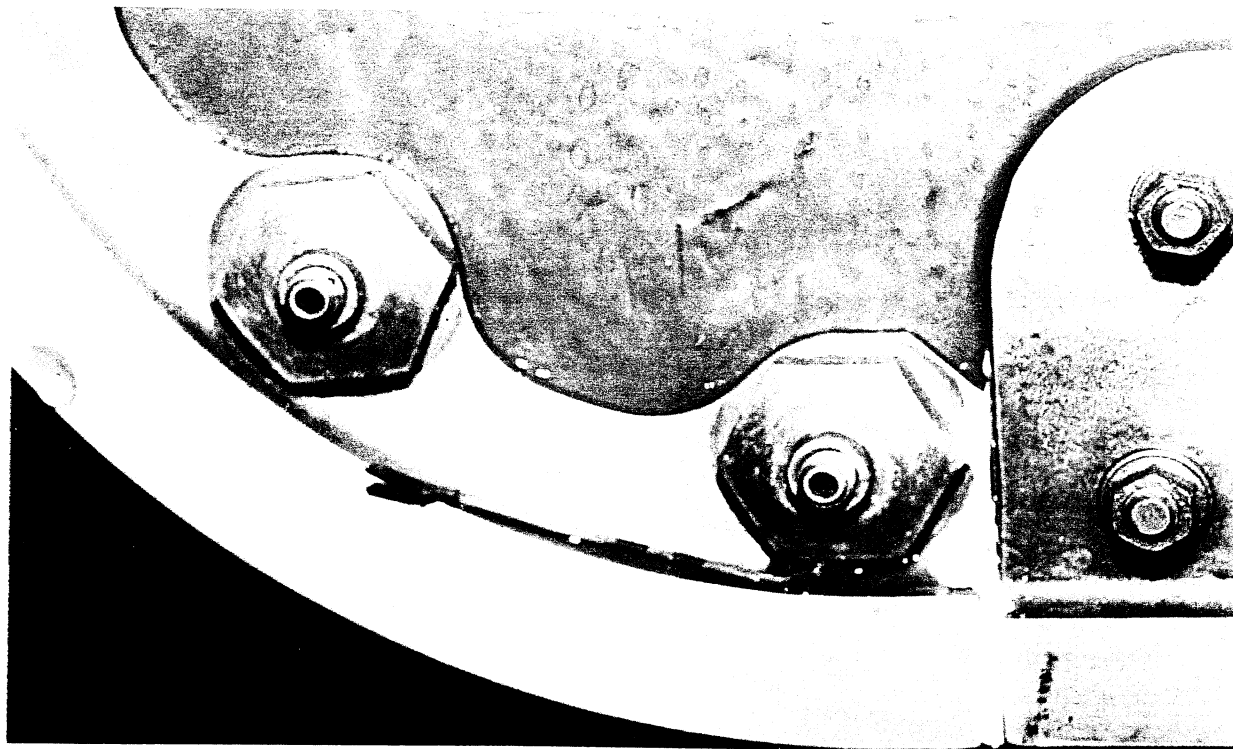
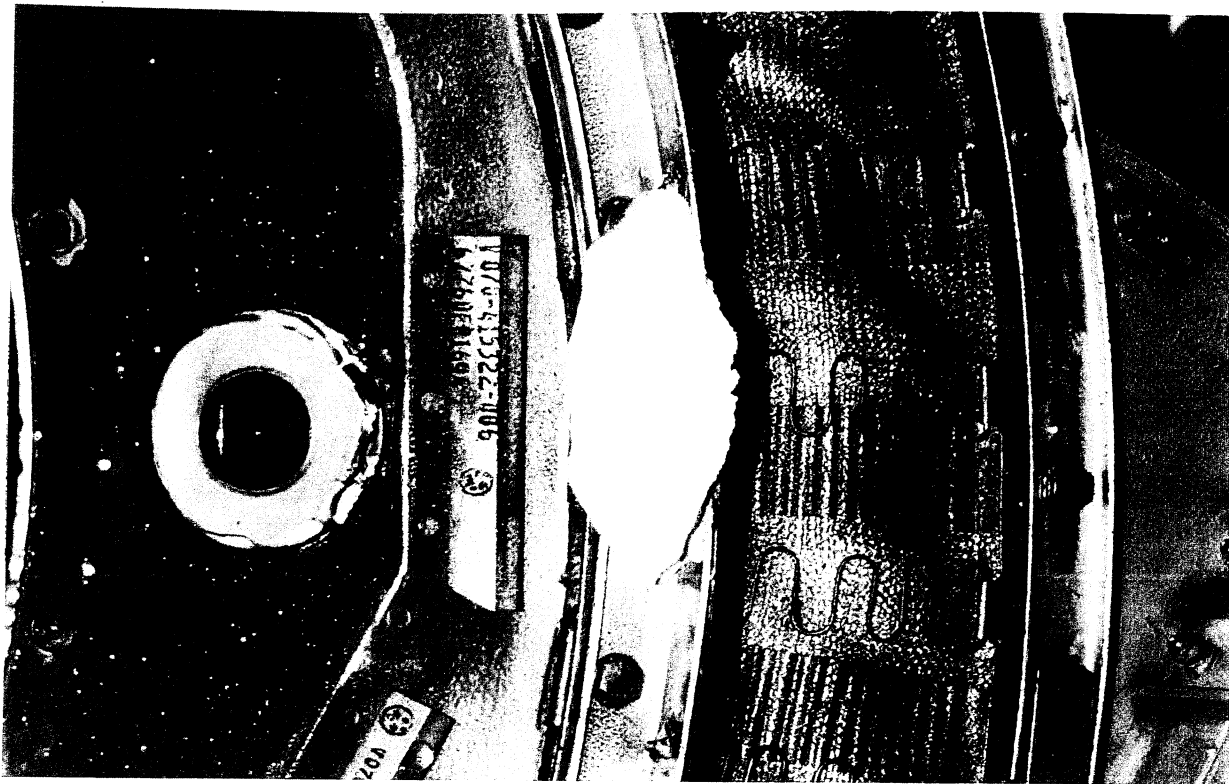


Photo 23: LO2 and LH2 ET/ORB umbilical debris

A piece (3.5" x 1.5" x .75") of umbilical closeout foam (pyro can closeout) was adhered to the umbilical plate near the LO2 disconnect. A 0.06-inch diameter by 1.5-inch long piece of wire with red insulation was found on the ET door LH2 side. This piece of wire was positively identified as a fragment of EO-2 ordnance firing cable.

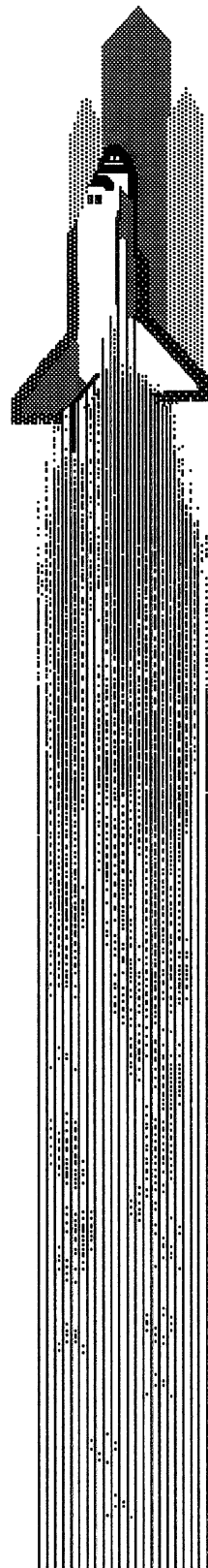
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Science Branch

STS-97 Summary of Significant Events

January 24, 2001





Space Shuttle

STS-97 Summary of Significant Events

Project Work Order - SN3CS

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Summary of Significant Events

1 STS-97 (OV-105): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-97 launch of Endeavour (OV-105) from Pad 39B occurred on Friday, December 1, 2000 at approximately 336:03:06:00.996 UTC as seen on camera E9. SRB separation occurred at approximately 03:08:04.8 UTC as seen on camera ET207.

On launch day, 21 of the 24 expected videos were received and screened. Cameras OTV159, ET204, and ET208 were not received.

Twenty-two launch films were screened and a report was sent to the Shuttle Program distribution on December 3, 2000. Twenty-two additional films were received for contingency support and anomaly resolution.

Three unusual events were seen during the review of the STS-97 launch videos and films that were elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report. (The launch + 4 day report consolidates the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria.) The three unusual events observed were:

97-01 A SRB holddown post stud hang-up on HDP #1.

97-02 Pulsating flames from the Orbiter +Z APU vent (at the base of the vertical stabilizer) from before SSME ignition through liftoff.

97-03 Very apparent body flap motion during ascent.

The 16mm umbilical well cameras did not fly on OV-105 during STS-97. The 35mm umbilical well TPS camera film was dark and not useable due to nighttime conditions at the time of ET separation. Handheld still photography of the ET was acquired following ET separation. (See section 2.7)

Video (acquired from cameras mounted on the SRB forward skirts) of the External Tank's +Y and -Y thrust panels was not acquired during ascent on STS-97.

Summary of Significant Events

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested. Pre-planned real-time analysis support was provided to the ISS AF-4A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-4A Imagery Overview Report.

1.1.3 Landing

Endeavour made a night landing on runway 15 at the KSC Shuttle Landing Facility on December 11, 2000 at 23:03:23.1 UTC. Eight videos and seven films were received.

The landing touchdown appeared normal. No anomalous events were seen during the Orbiter approach, landing, and landing rollout.

Post landing, a sink rate analysis of the STS-97 main landing gear was performed for the main gear touchdown. See Section 2.9.

The drag chute deploy sequence appeared normal on the landing imagery. See Section 2.8. Venting from the APU vent located at the forward edge of the base of the vertical stabilizer was seen during the landing roll-out and after wheel stop. Venting from the APU during landing has occurred on previous missions.

According to the pre-mission agreement, the STS-97 landing films were not screened due to budgetary constraints.

Summary of Significant Events

2 Summary of Significant Events

2.1 Findings Elevated to the Launch +4 Day KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Report

97-01: RSRB Holddown Post M-1 Stud Hang-up



Figure 2.1 (A) RSRB Holddown Post M-1 Stud Hang-up

A SRB holddown post stud hang-up was seen at RSRB holddown post M-1. The holddown post stud appeared fully extended before it released. The stud appeared to oscillate back and forth (twang) before falling back into the holddown post. The approximate time that the bolt appeared fully extended was 03:06:01.569 UTC. The time for the bolt to retract from full extension until the bolt was lost from sight in the holddown post shoe was 0.203 seconds (+/- 0.01 seconds). Using the provided 3.5 inch diameter of the bolt, the visible length of the M-1 bolt was estimated to be approximately 9.3 inches. The HDP M-1 shoe was estimated to have moved upward (+X direction) approximately 2.3 inches at the time of maximum bolt extension. No frangible nut debris from the M-1 DCS was seen during liftoff. The -Y PIC wire from the HDP M-1 remained attached and finally released at 03:06:01.427 UTC and the +Y PIC wire released at 03:06:01.579 UTC. Holddown post hang-ups were seen on STS-92 (and other previous missions) and are under investigation by the Shuttle program. (Camera E9)

Summary of Significant Events

97-02: Pulsating Flames from the Orbiter APU Vent

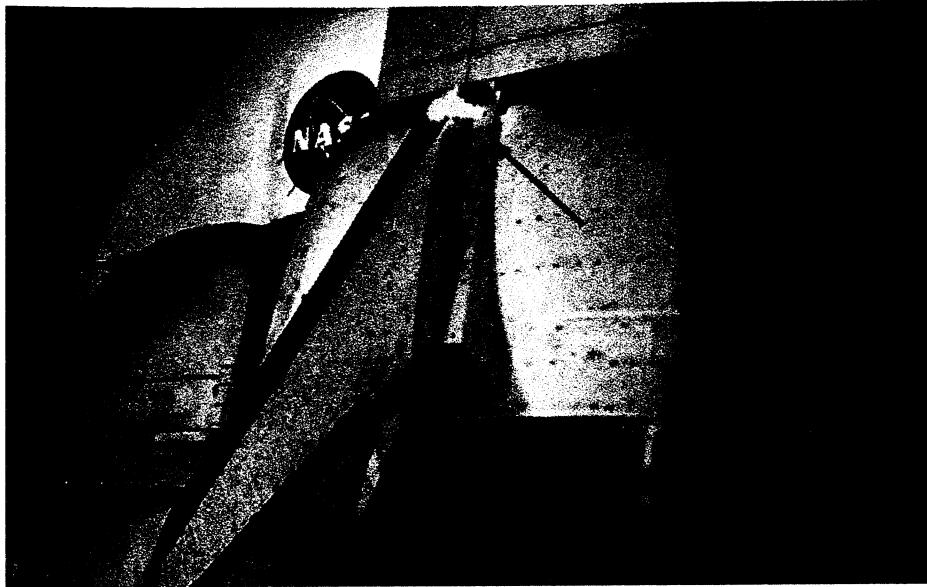


Figure 2.1 (B) Pulsating Flames from Orbiter APU

Pulsating flames from the Orbiter +Z APU vent forward of the base of the vertical stabilizer were visible from before SSME ignition through liftoff. The length of the flames was estimated to be between five to seven feet. The first time the APU flame was seen was prior to SSME ignition at 03:05:49.766 UTC on camera E63. The last time the APU flame was seen was approximately three seconds after liftoff (prior to the vehicle clearing the tower) at 03:06:04.032 UTC. The time period that the flames were (periodically) visible was 12.27 seconds. The time period between the visible flame pulses was approximately 0.66 seconds. Flames from the Orbiter APU vent were not previously seen during recent launches. Imagery from night launches on STS-92, STS-106, STS-101, STS-103, STS-93, and STS-96 was re-screened and no indications of flames from the APU vent were found. (Cameras E2, E36, E52, E63, E222)

97-03: Body Flap Motion During Ascent

Body flap motion during STS-97 ascent was very apparent (03:06:34 through 03:07:02 UTC). Motion of Shuttle Endeavor (OV-105) body flap during ascent was measured using imagery from long-range tracking camera E207. The following is a description of the analysis and results, including plots for out-of-plane displacements and frequencies of oscillation.

Camera E207 is a 35mm motion picture film camera that operates at 64 frames-per-second. The frames from this film camera were transferred to video to allow digital tracking analysis. Motions of the port and starboard tips of the body flap and two reference points on the vertical stabilizer were tracked for 5.5 seconds beginning at 48.0 seconds MET, during which time the body flap oscillations were most apparent. Figure 2.1 (C) shows the first frame in the analysis sequence with identifications for the four tracked points along with a fifth point, the midpoint of the body flap, which was calculated. The points were tracked automatically with a

Summary of Significant Events

commercially available tracking program¹ except for the starboard body flap tip which was tracked manually using the digitized imagery. The primary reference point corresponds with the aft base of the vertical stabilizer. The secondary reference point corresponds to a point forward of the primary point, near the base of the hinged portion of the vertical stabilizer.

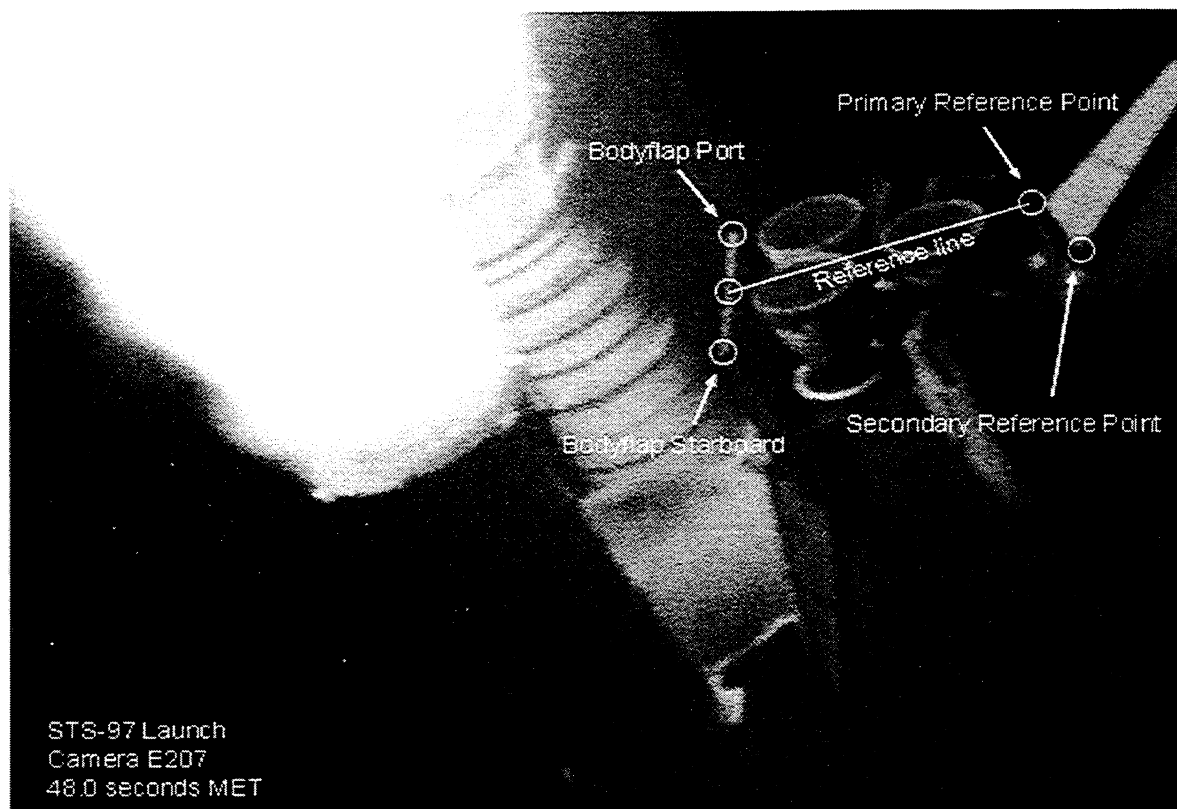


Figure 2.1 (C) Long-range Tracking Camera E207 Showing Tracked Points.

Gross motion of the Orbiter within the frame was removed from the raw data by comparing the motions of the two tips of the body flap with the motion of the primary reference point. The midpoint of the body flap was calculated for each frame and a reference line connecting this midpoint and the primary reference point was determined. This reference line, which has a known object length of 292.5 inches, was then used for scaling and to account for the gradual changes in scale and rotation during the sequence. (Small rapid variations in the length of the reference line due to the body flap motion were smoothed out in the scale calculation by fitting a second order polynomial curve to the line length as a function of time.) Motion of the body flap in the direction parallel to the reference line was assumed to be in the direction out of the plane of the body flap. All deflections described here refer to this “out-of-plane” direction. The secondary reference point was chosen for the high contrast pattern found in this location and was used in combination with the primary reference point to measure tracking accuracy.

Time histories were generated for the out-of-plane motion of the port and starboard body flap tips and for the body flap midpoint. Torsional motion of the bodyflap was also calculated by

¹ The software was the Nanotrack tool in the ISee package (version 5.1.3) developed by Inovision Corporation.

Summary of Significant Events

taking the difference between port and starboard out-of-plane motions. Any slight residual linear trends were removed from these tracks to obtain relative oscillatory deflections. Plots of the port and starboard deflections are given in figures 2.1 (D) and 2.1 (E). Maximum peak-to-peak deflections are listed in column 2 of Table 2.1. An estimate of the power-spectral-density was calculated for the first four seconds of each track using a commercially available signal processing software package². Figures 2.1 (F), 2.1 (G) and 2.1 (H) show these plots of power-spectral density and the dominant oscillatory frequencies are listed in column 3 of Table 2.1 (A).

Track point	Maximum peak-to-peak motion in inches	Dominant oscillation frequencies
Port tip	4.9	8.5 Hz
Starboard tip	6.8	8.4 Hz, 15.1 Hz
Midpoint	5.3	8.5 Hz
Torsional	5.1	12.4 Hz, 15.1 Hz

Table 2.1 (A) Summary of Body Flap Motion Peak Amplitudes and Frequencies.

Tracking uncertainty was estimated to be +/- 0.6 inches for the port tip, which was tracked automatically, and +/- 1.3 inches for the starboard tip, which was tracked manually. The automatic tracking uncertainty was obtained by measuring the motion of the secondary reference point in the same manner as for the body flap points. This motion was essentially random with a standard deviation of 0.35 pixels. The randomness is evidenced by the power spectral density curve for this point which shows no significant oscillatory motion. It peaks below a magnitude of 0.12 for all frequencies, and is entirely below 0.04 in magnitude if the first peak at 0.9 Hz is dismissed. The manual tracking uncertainty was taken to be +/- 0.75 pixels (based on a previous study conducted by this group) which translated to 1.3 inches after the average scale of 1.7 inches-per-pixel was applied. Uncertainty in the scale calculation was estimated to be less than five percent. Because the tracking uncertainty was over ten percent of the maximum amplitude measured for the port tip and nearly twenty percent for the starboard tip, the tracking uncertainty was clearly dominant for all measures.

	STS-84 (OV-104)	STS-86 (OV-104)	STS-97 (OV-105)
Body flap maximum displacement (inches):			
Starboard tip	6-8	4	7
Port tip	8	4	5
Frequency (Hertz):			
Global Frequency	8	8	8.5
Torsional Frequency	Not dominant	13	12.4, 15.1

Table 2.1(B): Comparison of STS-97 Body Flap Motion with Motion Measured on STS-84 and STS-86

² This was the Signal Processing Toolbox in Matlab 5.0, by The MathWorks Inc. In this toolbox we used the recommended Welch method for power spectral density estimation and applied a Hanning window (equal in size to the sequence length of 256) to reduce side-lobe interference.

Summary of Significant Events

The STS-97 body flap motion peak-to-peak displacement and frequency data derived from imagery is compared to the body flap motion data obtained from the STS-84 and STS-86 imagery in Table 2.1 (B).

The almost seven inch amplitude of the body flap motion seen on STS-97 is higher than that seen on STS-86 and similar to that seen on STS-84. The global frequency is approximately the same for the three missions. The STS-97 torsional frequency is similar to STS-86.

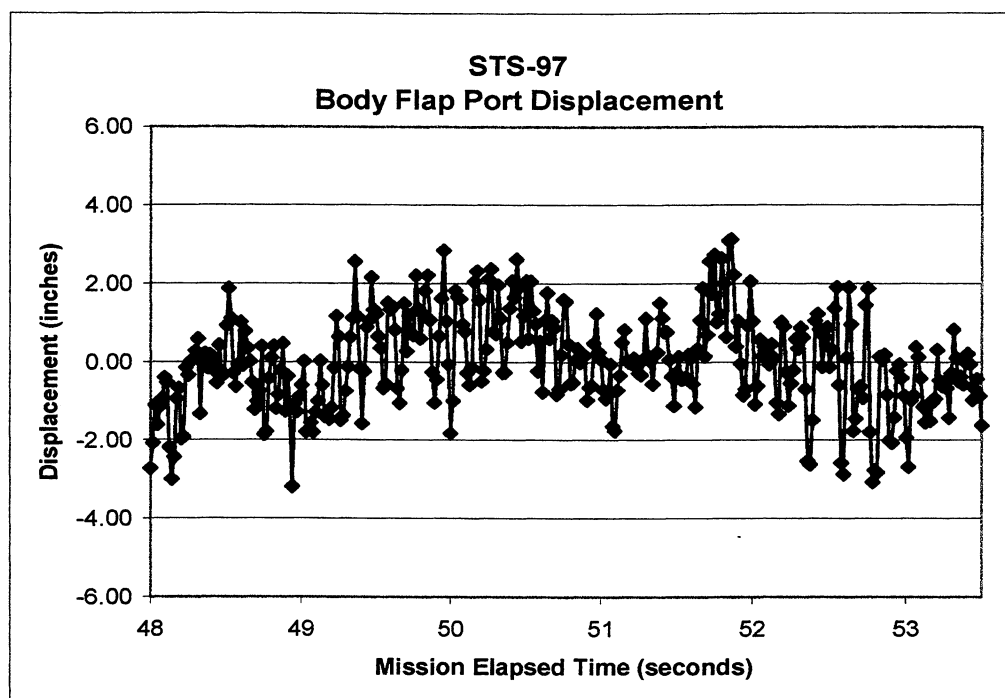


Figure 2.1 (D) STS-97 Body Flap Port Side Displacement

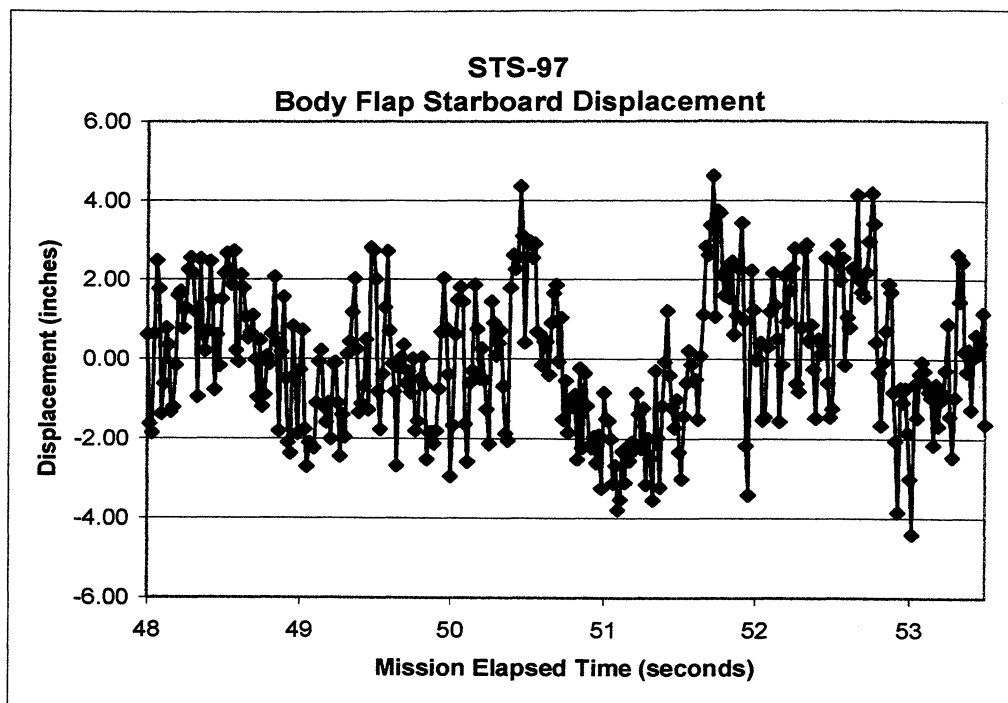


Figure 2.1 (E) STS-97 Body Flap Starboard Side Displacement

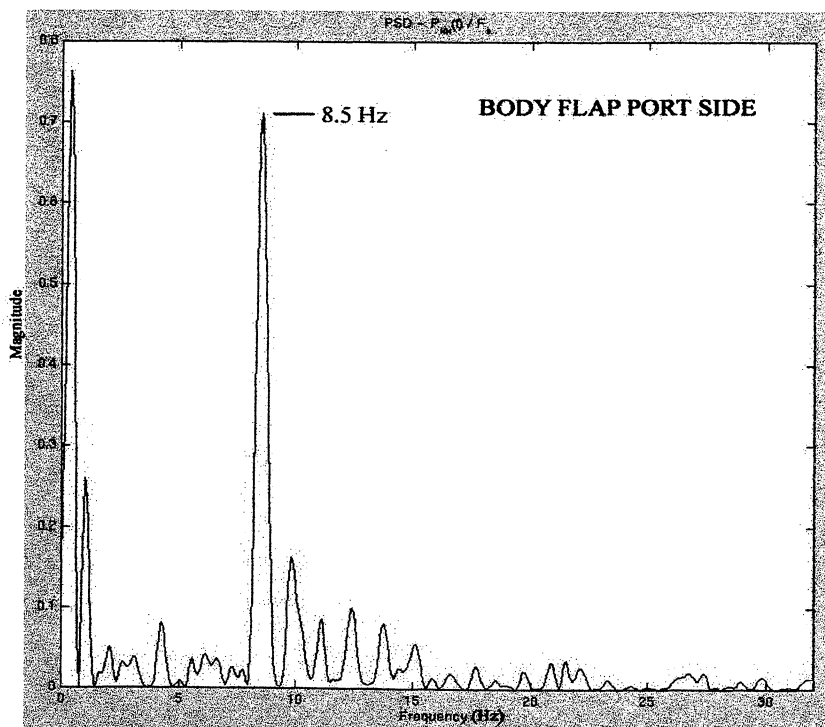


Figure 2.1 (F) STS-97 Body Flap Port Side Power Spectral Density

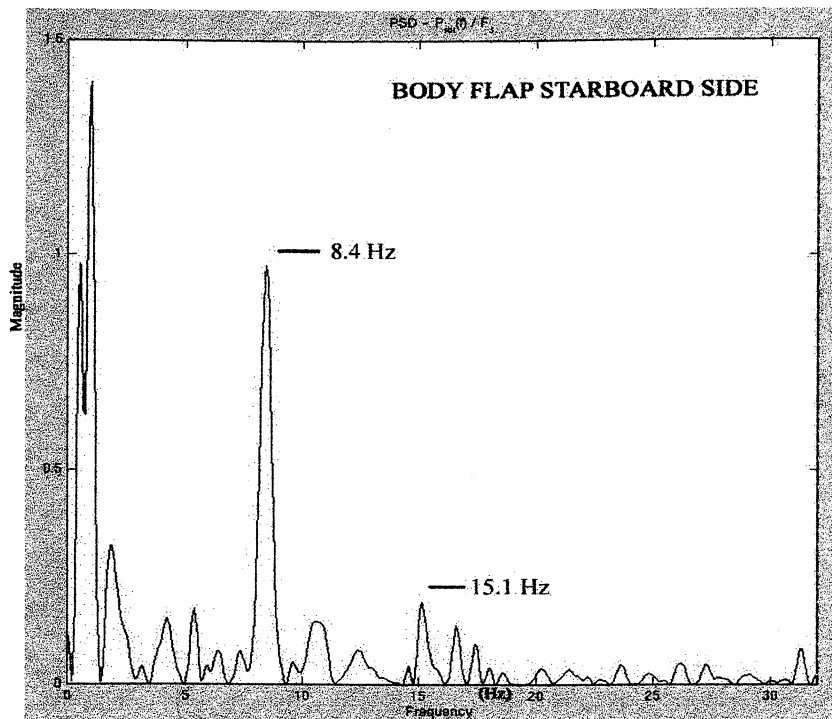


Figure 2.1 (G) Body Flap Starboard Side Power Spectral Density

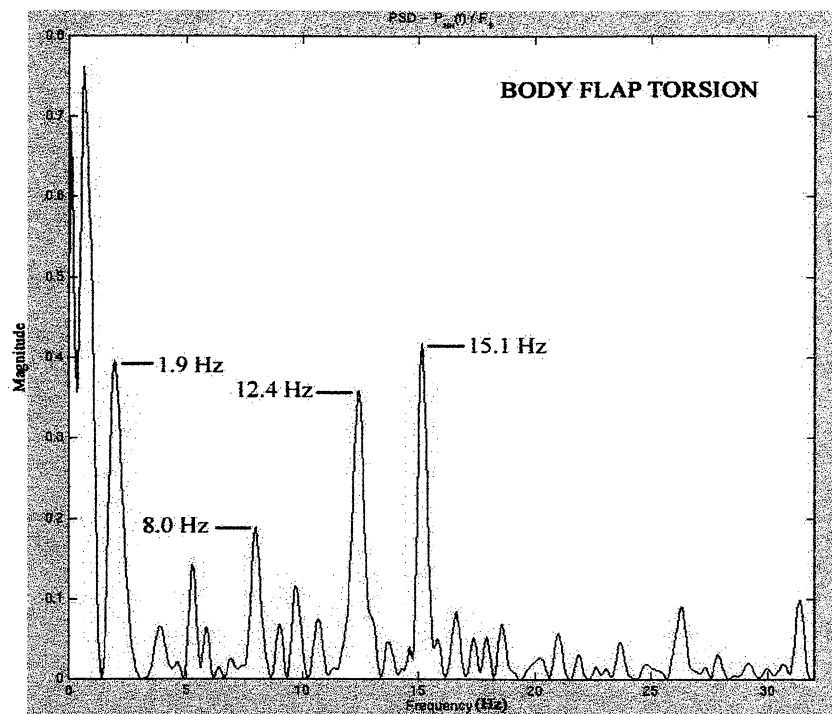


Figure 2.1 (H) STS-97 Body Flap Torsional Motion Power Spectral Density

Summary of Significant Events

2.2 Other Concerns Elevated to Program Management Prior to Landing

2.2.1 Vapor from Rudder Speed Brake during Ascent

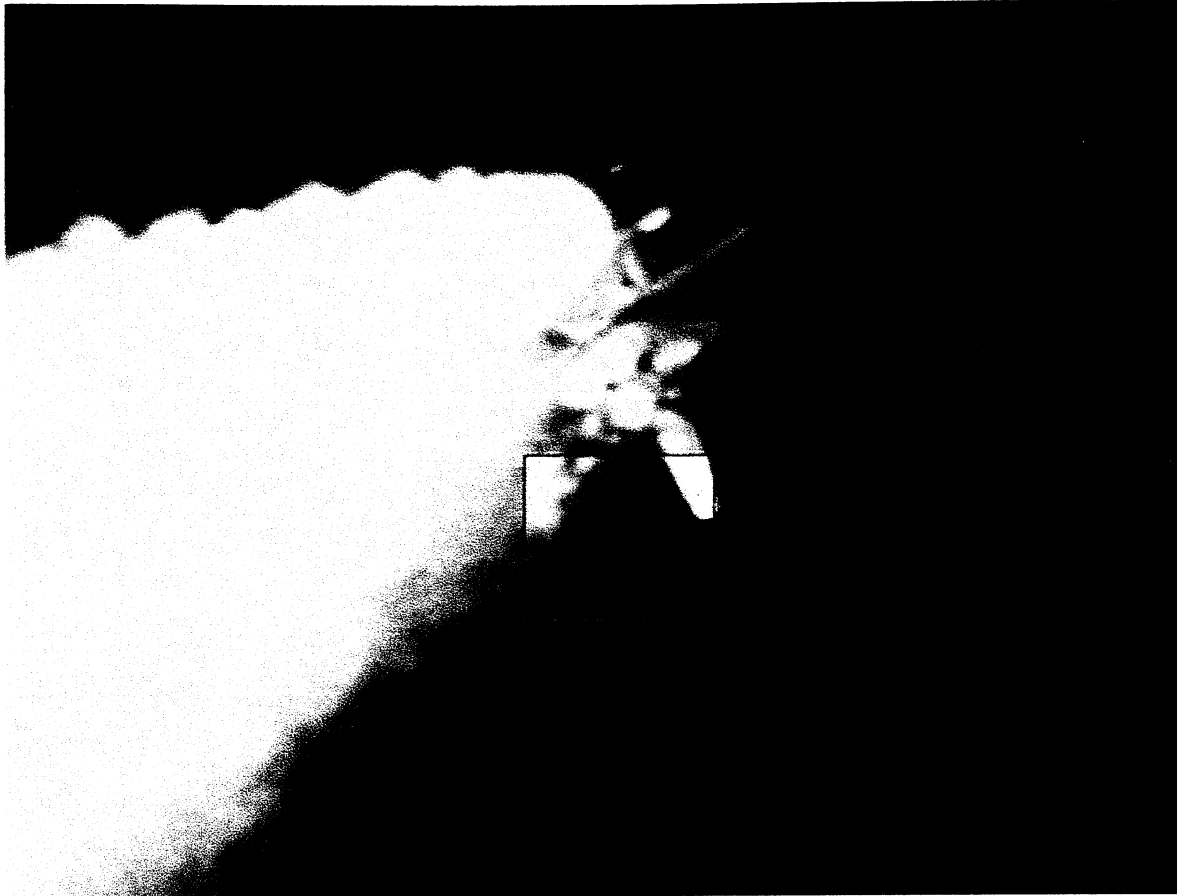


Figure 2.2.1 Vapor from Rudder Speed Brake during Ascent (Camera E222)

A light-colored trail of vapor was seen at the mid-portion of the aft edge of the rudder speed brake during ascent between 03:06:45.699 and 03:06:46.899 UTC. A portion of the vapor trail gave the appearance of possibly containing a solid piece(s) of debris. When the vapor trail contacted the SRB exhaust plume a slight color change was detected. White-colored streaks off the Orbiter right wing were seen on previous missions STS-26 and STS-101 that were concluded, post landing, to have been caused by disintegrating tile material. The streak seen on STS-97 was smaller and less apparent than the STS-26 and STS-101 streaks. KSC reported that no tile damage sites were observed on the vertical stabilizer leading edge during the post-landing inspections. It is possible that this vapor trail was atmospheric condensation. (Camera E222)

Summary of Significant Events

2.2.2 Dark Debris near ET Aft Dome during Roll Maneuver



Figure 2.2.2 Dark Debris near ET Aft Dome during Roll Maneuver (Camera ET207)

Dark appearing, somewhat irregular shaped, debris were seen near the ET aft dome during the roll maneuver on launch video ET207. The debris were visible for approximately 0.3 seconds. The first piece of debris was seen at 03:06:14.123 UTC. The last time debris was seen was 03:06:14.422 UTC.

The following is a description of the debris seen on Camera ET207:

Initially (03:06:14.123 UTC), a single piece of debris was seen coming from underneath the ET aft dome from the general direction of the Orbiter fuselage. The debris was highlighted against a background of white smoke.

At 0.05 seconds after the debris was first seen (03:06:14.172 UTC) the debris appeared to split into two pieces. However it could not be determined if the second debris piece was, in fact, debris or if it was a shadow of the single piece of debris. At 0.133 seconds (03:06:14.256 UTC) three to four dark-colored objects were visible. However, on closer inspection it was concluded that the video frame imaged two pieces of debris (or a piece of debris and its shadow) and that the other debris was actually the same debris pieces or its shadow caught in

Summary of Significant Events

motion on two separate video fields that made up the video frame.

At 0.149 seconds (03:06:14.272 UTC) three dark objects were clearly visible.

At 0.182 seconds (03:06:14.305 UTC) no debris was visible because of the smoke.

At 0.216 seconds (03:06:14.339 UTC) one piece of debris was again visible. By this time the debris had moved in an apparent +x direction against the background of the ET aft dome TPS.

At 0.266 seconds (03:06:14.389 UTC) two dark-colored objects were visible but, again, it is possible that the second object was a shadow of the first.

At 0.299 seconds (03:06:14.422 UTC) a single dark-colored object was last seen.

A single, small dark-colored piece of debris near the ET aft dome was also detected on the launch camera E52 film at the same time it was seen on the ET207 view (between 03:06:14.187 and 03:06:14.291 UTC). The debris seen on the camera E52 view was first seen near the +Y aft corner of the body flap moving diagonally in an aft direction across the ET aft dome toward the RSRB aft skirt.

Measurements were made on the clearest views from camera ET207 of the largest appearing debris object. The diameter of the RSRB (12.17 feet) was used for scaling. The largest debris measurement obtained was 5.0 inches in the longest dimension at 03:06:14.272 UTC. The debris measured approximately 4.2 inches in the longest dimension at both 03:06:14.339 and 03:06:14.356 UTC. The accuracy of the debris measurements is estimated to be +/- 1 inch.

No debris was seen to detach from the charred area on the ET aft dome and no areas of missing TPS on the ET aft dome were confirmed. Normally if debris is charred insulation, it will show a light-colored side as it tumbles (although it is possible that in the short amount of time that the debris were visible, only the dark side faced the camera). Considering both the ET207 and E52 views, a single piece of debris (that may have subsequently broken into two or more pieces) was first visible between the +Y aft corner of the body flap and the -Y region of the ET aft dome. This debris appeared to originate from an unidentified area between the Orbiter and the ET forward of the trailing edge of the body flap.

None of the Orbiter tile damage found during the KSC post landing inspection was correlated to the dark-colored debris seen near the ET aft dome during ascent. One possibility is that the dark debris was butcher paper from the ET umbilical area.

Summary of Significant Events

2.3 Other Observations

2.3.1 Debris from SSME Ignition through Liftoff

Similar to previous missions, multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the -Z side of the body flap during SSME ignition through liftoff. Several pieces of the debris were seen to contact the Orbiter LH2 umbilical well doorsill (03:05:56.584, 03:05:57.952, 03:05:58.720 UTC). Also, a single piece of umbilical ice debris contacted the LO2 press line (03:05:57.585 UTC). No damage to the launch vehicle was detected. (Cameras OTV109, OTV154, OTV163, E1, E4, E5, E18, E31, E34, E52, E76)

Four to five unidentified pieces of light-colored debris (possibly ice from the forward LO2 feed line bellows) were seen forward of the LO2 ET/Orbiter umbilical falling along the Orbiter inboard right wing tiles just before liftoff (03:06:00.75 UTC). (Cameras OTV154)

A small light-colored piece of debris was seen falling from somewhere forward of the left SRB/ET aft attach brace during liftoff (03:06:01.752 UTC). It was not determined where this debris originated from but possibilities would be ice / frost from the forward ET GH2 vent or ice / frost from the forward LO2 feedline bellows. (Camera E31)

Five or more light-colored pieces of debris were seen traveling from the area of the RSRB flame duct (probably SRB throat plug material) in a northerly direction away from the launch vehicle after SRB ignition (03:06:02.12 UTC). None of the debris was seen to contact the launch vehicle. Similar debris from the SRB flame ducts has been seen on previous missions. (Cameras KTV4B, E4)

2.4 Debris during Ascent



Figure 2.4 (A) Debris near SSME Exhaust Plumes

As observed on previous missions, multiple pieces of debris (umbilical ice and RCS paper) were seen near the SSME exhaust plumes and falling aft of the launch vehicle during ascent (03:06:13.842, 03:06:16.295 - 03:06:34.813 UTC). During this same time period, several pieces of light-colored debris (probably umbilical ice) were seen on the -Z side of the body flap (03:06:17.963 - 03:06:30.676 UTC). Later, a single piece of light-colored debris (also probably umbilical ice) traveled aft along the body flap (03:06:53.198 UTC). (Cameras KTV21B, ET207)

Other examples of debris sightings were:

- E54 forward RCS paper debris at mid fuselage level after tower clear (frames 1642, 1773)
- E52 multiple pieces of debris near vertical stabilizer and aft of vehicle at 7.2 seconds MET
- E222 spray of RCS paper debris at 17.2 seconds MET
- E222 umbilical ice debris along body flap at 27.6 seconds MET
- E222 debris fell into SSME exhaust plume at 30.9, 32.7 seconds MET
- E223 large spray of debris near SSME #1 exhaust plume at ~38.5 seconds MET (frame 3607)
- E222 debris near vertical stabilizer at 44.7 seconds MET

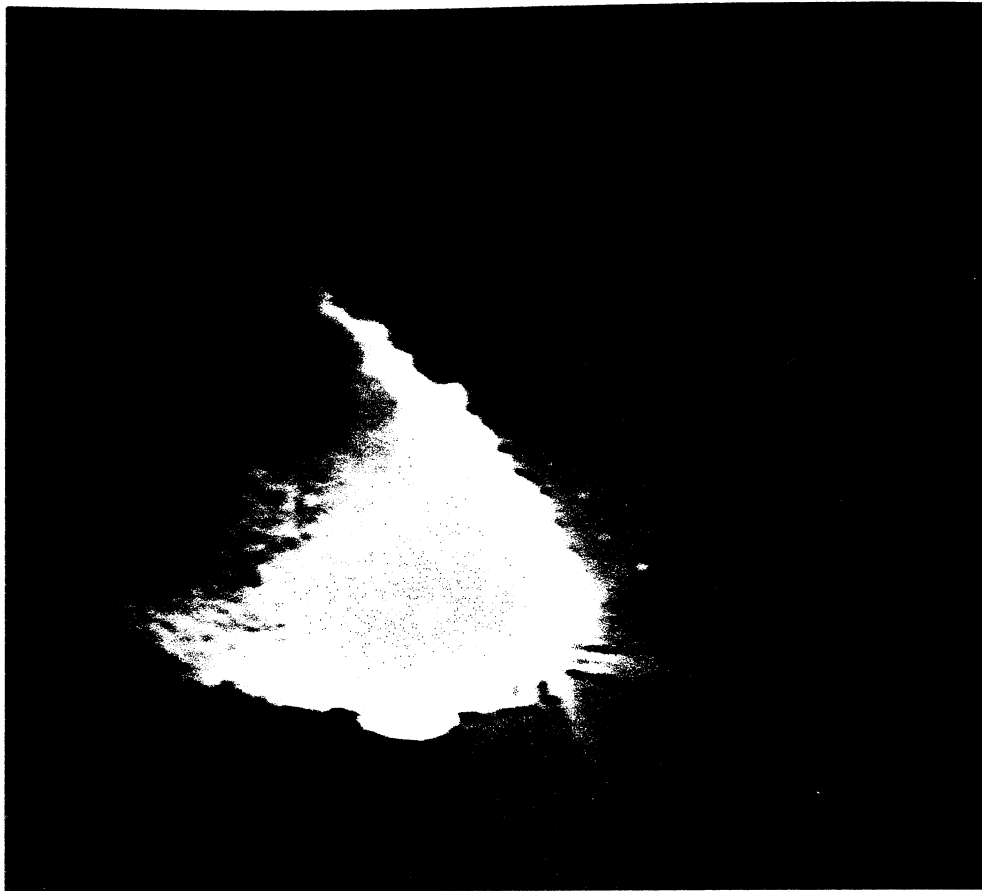


Figure 2.4 (B) Debris Exiting RSRB Exhaust Plume (Camera KTV4B)

Multiple pieces of light-colored debris (probably instafoam or slag) were seen exiting the SRB exhaust plume starting at approximately 70 seconds MET (03:07:11.744, 03:07:12.611, 03:07:15.814, 03:07:17.249 UTC). Debris exiting the SRB exhaust plume during ascent has been seen on previous mission imagery. During the last mission (STS-92), similar debris was also seen at 70 seconds MET. (Cameras KTV4B, KTV5)

Debris was also seen exiting the SRB exhaust plumes on the long range tracking camera films at:

E212	~35.9 seconds MET (frame 1350, two pieces)
E222	34.2 seconds MET
E207	~71.3, ~72.5, ~72.7 seconds MET (frames 4470, 4546, 4559)

A single large orange-colored piece of probable umbilical purge barrier material was seen to detach from the ET/Orbiter umbilical and fall aft during ascent at ~17.1 seconds MET (frame 1002). Umbilical purge barrier material debris during ascent has been seen on previous mission imagery. (Camera E207)

Summary of Significant Events

2.5 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal on the high-speed engineering films and the SSME Mach diamonds appeared to form in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.5 (A) are from camera film E19. (Cameras E19, E20, E76)

SSME	TIME (UTC)
SSME #3	03:05:57.723
SSME #2	03:05:57.914
SSME #1	03:05:58.113

Table 2.5 (A) SSME Mach Diamond Formation Times

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, forward of the base of the vertical stabilizer, and extending above the aft edge of the right OMS pod during SSME ignition (03:05:55.82 UTC). Orange vapor forward of the SSME rims has been seen on previous mission films and videos, particularly on night launches. (Cameras OTV170, OTV171, E2, E4, E5, E18, E19, E36, E52)

Faint light-colored streaks, typical of previous missions, were seen extending aft from the SSME nozzle rims prior to and during liftoff. The times for the light-colored streaks are given in Table 2.5 (B). (Cameras E2, E5, E19, E20, E52, E76):

SSME	TIME (UTC)
SSME #1	03:05:59.445, 03:06:01.799, 03:06:01.844
SSME #2	03:06:01.853
SSME #3	03:06:02.668

Table 2.5 (B) Light-colored Streaks Prior to and during Liftoff

Typical of previous missions, small areas of tile surface coating material erosion were seen on the base heat shield outboard of SSME #3 (03:05:56.608 UTC), on the base heat shield near the base of the +Y RCS pod (03:05:56.671 UTC), and on the tip of the -Y RCS stinger prior to liftoff. Less than usual amounts of tile damage were found on the base heat shield according to the KSC Post Landing Inspection Report. (Cameras E19, E20)

SRB ignition was at 03:06:00.996 UTC based on the observation of the PIC firing at RSRB holddown post M-1. (Camera E9)

The left and right SRB GN2 purge lines appeared intact during the time period they were visible before being obscured by exhaust plumes. KSC reported in the Post Launch Debris Inspection Report that both of the SRB aft skirt GN2 purge lines were intact. (Cameras E8, E13)

Summary of Significant Events

2.6 Ascent Events

The outgassing and vapors near the ET aft dome during early ascent appeared typical to that seen on previous mission films and videos. (Cameras ET207)

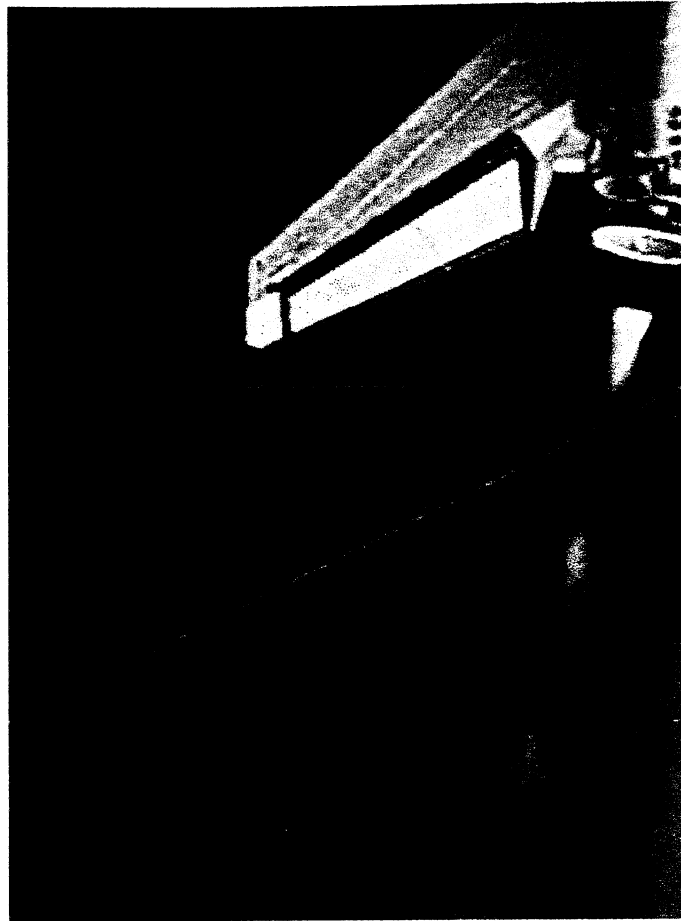


Figure 2.6 (A) Vapor from Drain on the Orbiter Speed Brake (Camera E52)

A faint vapor trail was seen trailing aft of the drain on the trailing edge of the Orbiter speed brake prior to the roll maneuver (03:06:05.9 UTC). The diagonal line in Figure 2.6 (A) is a grounding cable that is attached to the lightning mast at the top of the Fixed Service Structure. Moisture streaming from the speed brake drain has been seen on previous mission imagery. (Camera E52)



Figure 2.6 (B) Flares in the SSME Exhaust Plume (Camera E222)

Light-colored flares (some seen to be debris induced) were seen in the SSME exhaust plumes during ascent on the intermediate and long range tracking camera films between 8 and 51 seconds after liftoff. Examples are:

KTV2, E52 03:06:08.703 UTC, 03:06:08.795 UTC, 03:06:08.888 UTC
E223 ~19.0 seconds MET (frame 1735)
E207 ~32.6 seconds MET (frame 1997)
E207 ~33.7 seconds MET (frame 2068)
E223 ~44.1 seconds MET (frame 4148)
E212 ~44.3 seconds MET (frame 1889)
E223, ET212 ~ 51.0 seconds MET (03:06:50.969 UTC, E223 frame 4810)

Flares in the SSME exhaust plumes have been seen on previous missions films and videos. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris appeared to be RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) (Cameras KTV2, ET212, E52, E207, E212, E222, E223)

Partially detached RCS paper was seen on the downward and upward firing RCS jets on the right RCS stinger after the roll maneuver. (E207)

Summary of Significant Events

2.7 Onboard Photography of the External Tank (ET-105)

2.7.1 Analysis of the Umbilical Well Camera Films

No External Tank or SRB separation photography was acquired on STS-97 with the umbilical well camera films.

2.7.2 16mm Umbilical Well Camera Films

The two 16mm umbilical well camera films were disabled preflight because of the investigation into an electric short problem.

2.7.3 35mm Umbilical Well Camera Film

The 35mm umbilical well TPS camera film was unusable due to the nighttime conditions at ET separation.

Summary of Significant Events

2.7.4 ET Handheld Photography

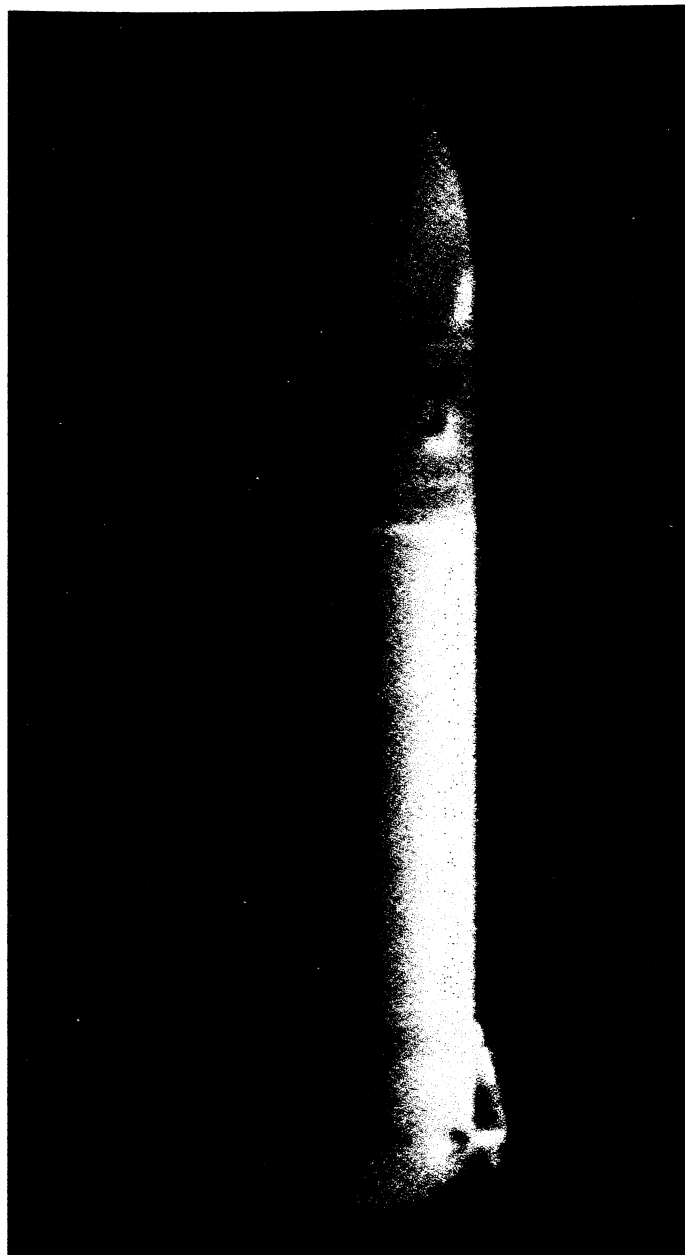


Figure 2.7.4 Handheld Camera View of the External Tank

No anomalous conditions were seen on the handheld imagery of the STS-97 External Tank (ET-105).

Views of the nose, the aft dome, and the -Y side of the ET were obtained. Views of the remaining sides of the ET were unusable due to the view angle and dark shadows on the surface of the ET caused by back lighting from the Sun. The level of detail on the ET that could be seen on the film was limited because of the large distance between the Orbiter and the

Summary of Significant Events

ET when the pictures were taken. The minimum resolvable object size on the STS-97 ET photos was estimated to be twelve inches.

The normal -Y SRB separation burn scar and aero heating marks were noted on the intertank and nose TPS of the ET. The visible portion of the -Y LO2 tank / Ojive TPS appeared to be in satisfactory condition. The black-colored intertank access door and the hydrogen intertank vent were visible and appeared normal. The extended ET/Orbiter forward attach bipod could be seen.

The -Y ET thrust panel appeared in satisfactory condition. No significant divoting of the TPS on the -Y thrust panel was confirmed from the hand held imagery. The +Y thrust panel was not imaged. No divots were seen on the -Y / -Z LH2 tank-to-intertank closeout flange. No divots or unusual marks were seen on the visible portions of the -Y LH2 tank TPS. No venting from the ET intertank vent was observed.

The following is a description of the handheld External Tank imagery:

Twelve handheld pictures of the External Tank (ET-105) were acquired using the handheld 35mm Nikon F5 camera with a 400mm lens on film roll 307. The lighting of the ET on the first five frames was adequate. A large portion of the ET was dark on the remaining seven frames because of the back lighting from the Sun. Timing data is present on the film.

The astronauts acquired the photography during the early OMS-2 maneuver from the heads-down position that was timed to coincide with the late crossing of the sunrise terminator by the ET. The first picture was taken at 03:34:57 UTC or 28:56 (minutes: seconds) MET. The distance of ET from the Orbiter was estimated to be approximately 4 km on the first photographic frame acquired.

2.7.5 ET Handheld Video

No handheld video was acquired because of the small size of the ET in the view finder by the time the ET had come into daylight.

Summary of Significant Events

2.8 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 2.8.

STS-97 Landing and Drag Chute Event Times from Video:

Event Description	Time (UTC)	Camera
Main gear door opening	346:23:03:05.1	EL17 IR
Left main gear tire touchdown	346:23:03:23.1	EL17 IR
Right main gear tire touchdown	346:23:03:23.2	EL17 IR
Drag Chute initiation	346:23:03:26.8	KTV15L
Pilot Chute full inflation	346:23:03:27.9	KTV33L
Bag release	346:23:03:28.4	EL17 IR
Drag chute inflation in reefed configuration	346:23:03:29.4	KTV33L
Drag chute inflation in disreefed configuration	346:23:03:33.0	KTV33L
Nose gear tire touchdown	346:23:03:35.0	EL17 IR
Drag chute release	346:23:03:52.4	LTV33L
Wheel Stop	~346:23:04:19.8	KTV33L

Table 2.8 Landing Event Times

Note: The symbol ~ means that the event was not clearly seen because of the limited light available during the night landing and the event time shown is approximate.

Summary of Significant Events

2.9 Landing Sink Rate Analysis

Image data from the centerline camera at the approach end of runway 15 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touch down for each of the landing gear was considered. Data points defining the main gear struts were collected on every frame (52 frames of data during the last second prior to touch down with respect to each landing gear; the speed of Camera E7 was slowed to 51.6185 frames per second presumably due to the night landing). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts (272 inches) was used as a scaling factor. The main gear midpoint height above the runway was calculated by the change in vertical difference between the main gear struts and the reference point on the runway. The left and right main gear heights were calculated from their corresponding gear strut and the reference point on the runway. A trendline for each of the main gear and the midpoint between the main gear was determined considering the height of the Orbiter above ground with respect to time. Sink rate equals the slope of each regression line.

The main gear sink rate for STS-97 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.9. The left main gear sink rate is relative to left main gear touch down; the right main gear and the midpoint between the main gear are relative to right main gear touch down. Plots describing the sink rates for the individual gears are shown in Figures 2.9 (A) and 2.9 (B).

Time Prior to Touchdown	Last 1.00 Second	Last 0.5 Seconds	Last 0.25 Second
Left Main Gear Sink Rate	3.7 ± 0.1 ft/sec	3.6 ± 0.1 ft/sec	3.4 ± 0.3 ft/sec
Right Main Gear Sink Rate	3.4 ± 0.1 ft/sec	3.2 ± 0.1 ft/sec	2.9 ± 0.4 ft/sec
Midpoint Main Gear Sink Rate	3.5 ± 0.1 ft/sec	3.2 ± 0.3 ft/sec	2.8 ± 0.3 ft/sec

Table 2.9 Orbiter Main (Left, Right, Mid) Gear Landing Sink Rate

Summary of Significant Events

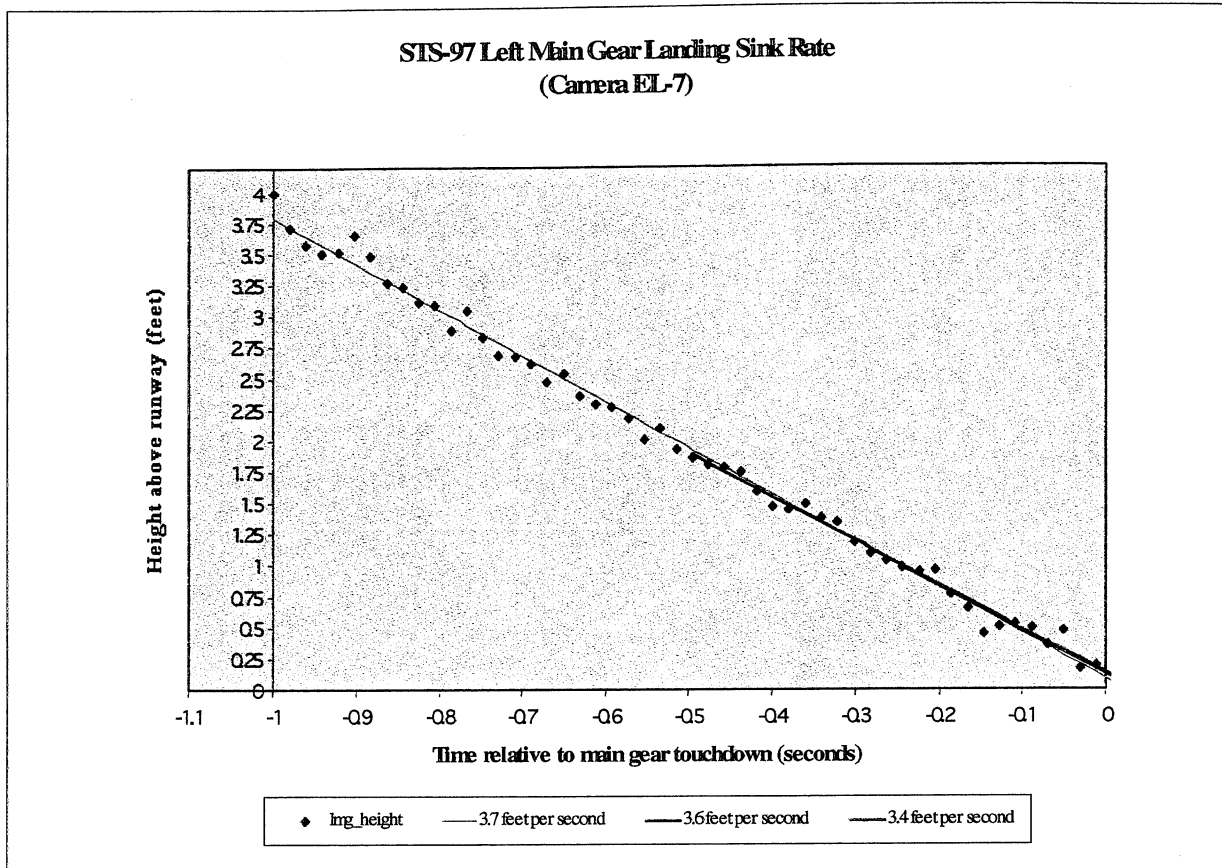


Figure 2.9 (A) Left Main Gear Landing Sink Rate

Summary of Significant Events

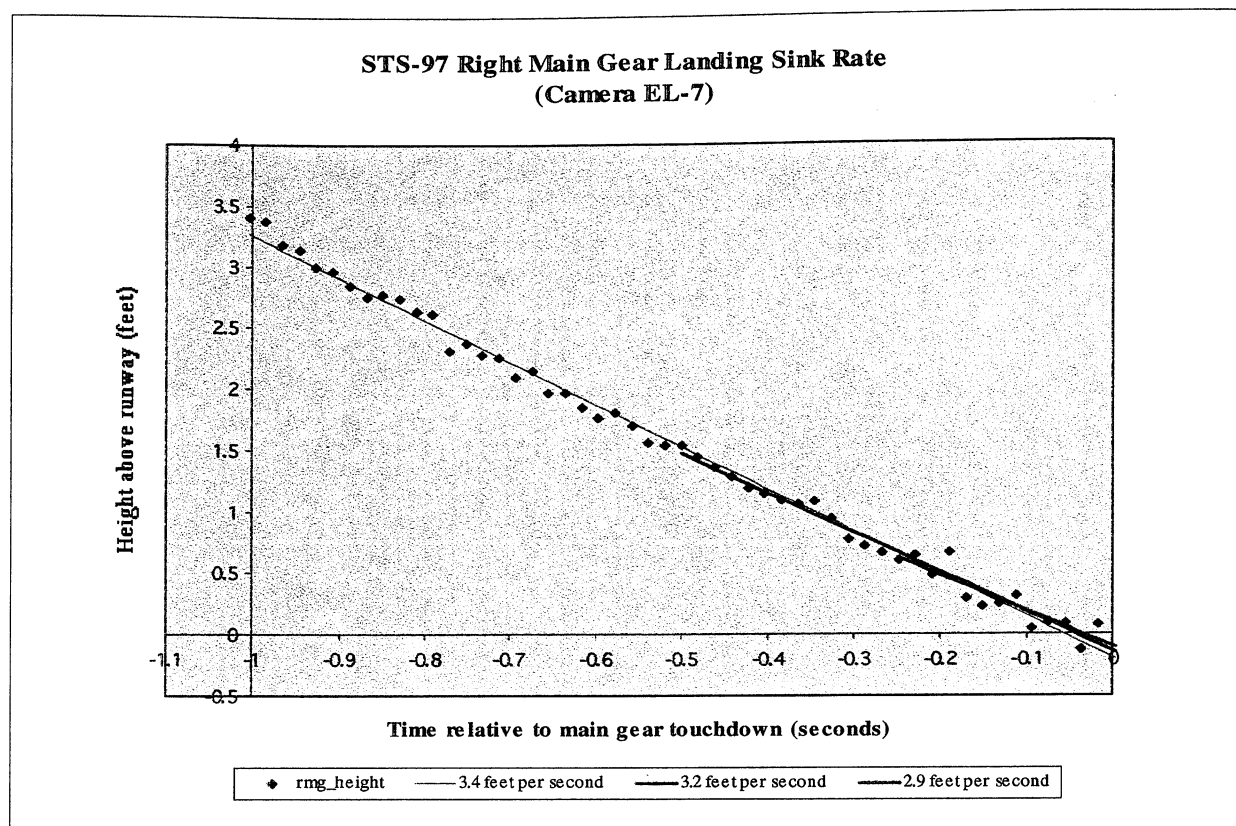


Figure 2.9 (B) Right Main Gear Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet / second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-97 vehicle was estimated to be 198,006 lbs.

Summary of Significant Events

2.10 Other

2.10.1 Normal Events

Normal events observed included:

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud (including water baffle material) after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

2.10.2 Normal Pad Events

Normal pad events observed included:

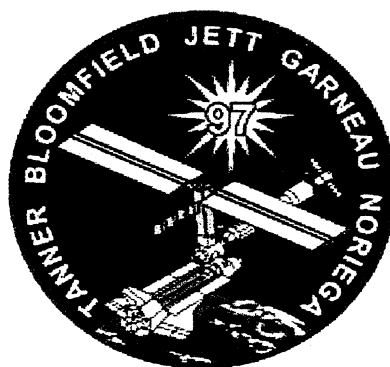
- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical disconnect and retraction
- LH2 and LO2 TSM door closures

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Shuttle Mission STS-97

Engineering Photographic Analysis Summary Report Marshall Space Flight Center



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*December 11, 2000
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Engineering Photographic Analysis Summary Report for STS-97



Launch of the one-hundred-first space shuttle mission, STS-97, the fifteenth flight of the Orbiter Endeavour (OV-105), occurred November 30, 2000, at approximately 9:06 PM Central Standard Time from launch complex 39B, Kennedy Space Center (KSC), Florida. Launch time was reported as 00:336:03:06:00.986 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Photographic Analysis Website:

Further information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts97/sts97.html>.

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD),
- Individual camera status and assessments,
- Annotated images of notable observations,
- Movies of select events, and
- Photographic Analysis Mission Summary Report (PDF format).

Photographic Coverage:

Sixty-one engineering photographic products consisting of launch video, ground-based engineering films and onboard film were received and reviewed at MSFC.

Imaging from two ground-based cameras was not available on this mission, film camera E208 and video camera OTV149. Film camera E63 had a very short run. TV4B was overexposed as the vehicle clears the tower. Tracking was not consistent in films E220 and E205. Also, in E205 footage, the vehicle was misframed, drifting in and out of the top of the frame. Numerous film-processing marks were observed on films E207, E220, and E223. There were no Umbilical well camera images for this mission.

Also noted on this mission was a format change for the electronic PADD information file.

Camera coverage received at MSFC for STS-97 is illustrated in the following table.

	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	5
Tracking	0	8	9
Onboard	0	1	0
Totals	24	16	21

T-Zero Times :

T-Zero times are determined from MLP cameras that view the SRB holddown posts numbers M-1, M-2, M-5, M-6, and M-7. These cameras record the explosive bolt combustion products. Normally, the PIC firing time from Holddown Post M-7 is not available because the doghouse cover obscures the combustion products.

Holddown Post	Camera	Time (UTC)
M-1	E9	336:03:06:00.994
M-2	E8	336:03:06:00.994
M-5	E12	336:03:06:00.995
M-6	E13	336:03:06:00.994
M-7	E11	336:03:06:00.996

SRB Separation Timing:

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at 336:03:08:04.899 UTC.

Anomalies:

Film Camera E9: Stud Hang-up on HDP M1

A stud hang-up was observed, from film camera E9, on RSRB Holddown Post M1. The Holddown Post shoe was pulled up with vehicle showing the spherical bearing. The stud appeared to be fully extended until separation from SRB. A twang was observed at separation from vehicle. After separation, the shoe returns to rest position and stud falls into HDP hole. Apparent minor debris was observed emanating from SRB foot hole on stud separation.

This observation was listed on the STS-97 Consolidated Film/Video Report.

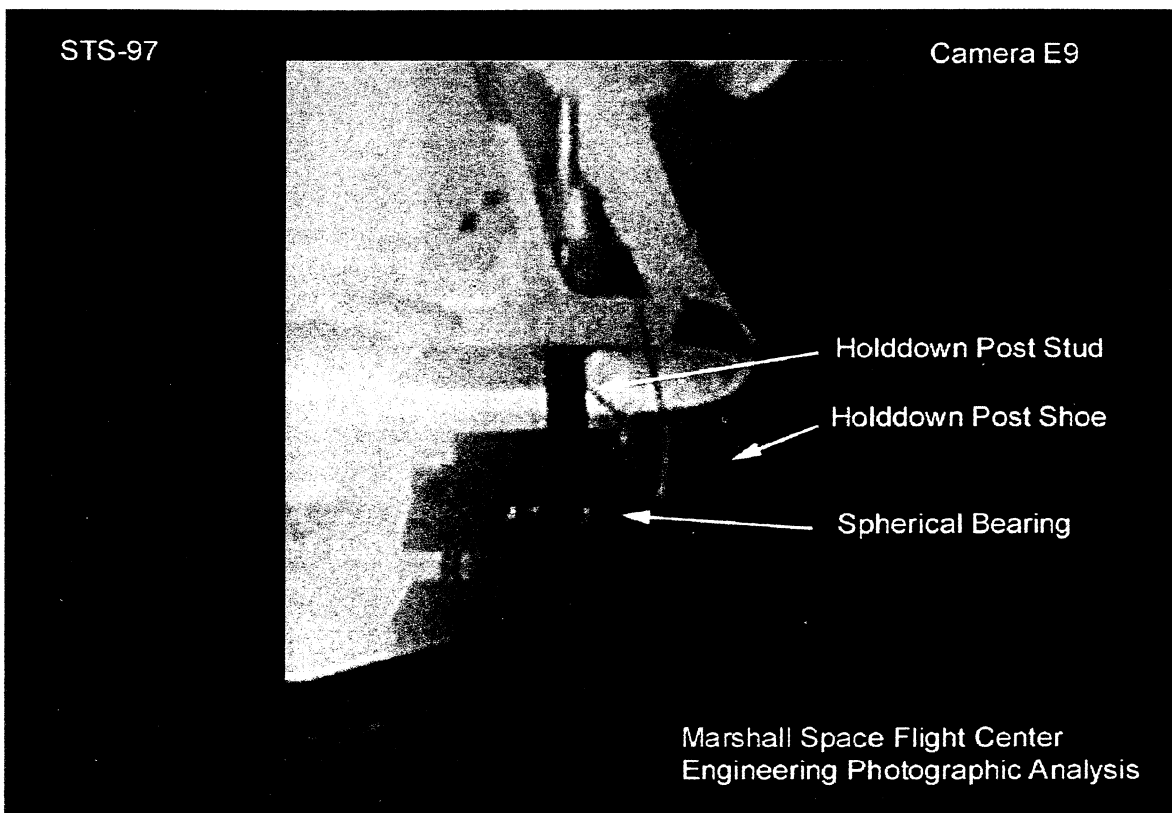


Figure 1. Stud Hang-up on HDP M1

Observations:

Video Camera OTV154: Ice from 17-inch Disconnects

Typical ice from 17-inch disconnect was noted. Also, ice fell through the field of view from possibly two sources forward of the disconnect. One source of debris apparently came from near the Orbiter and the other near the right SRB.

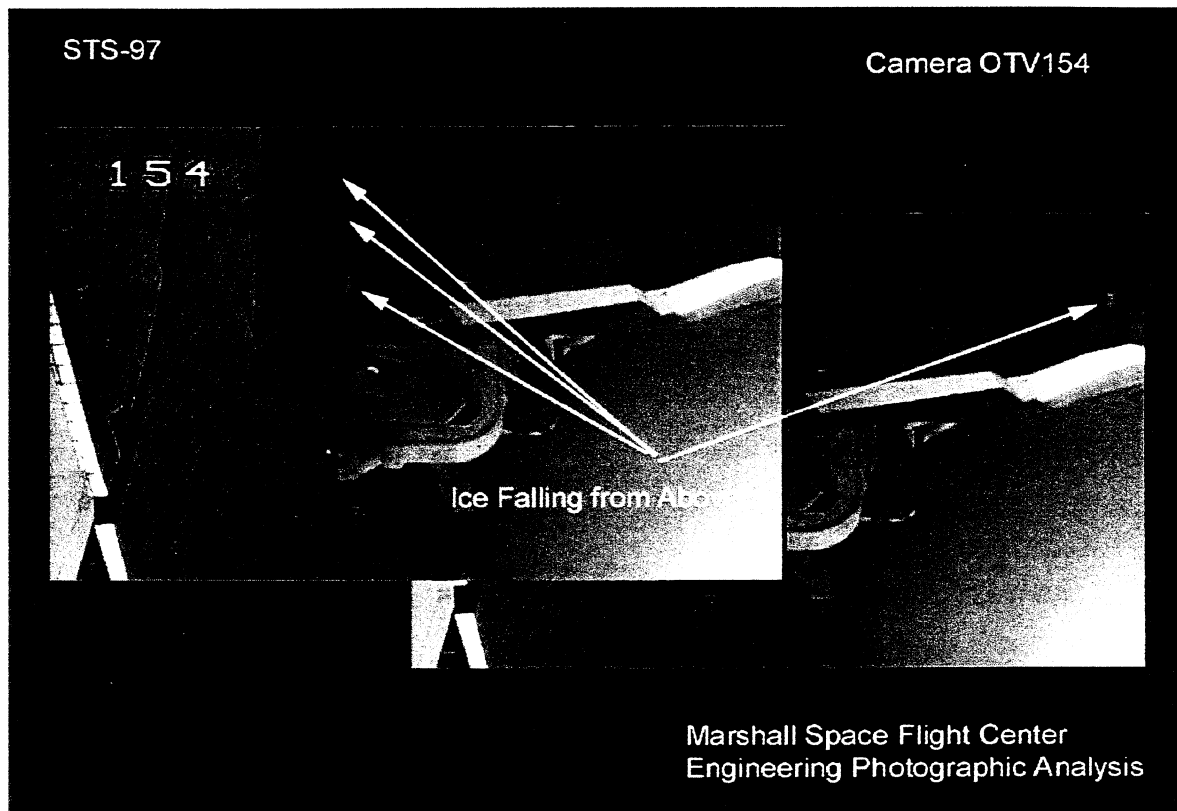


Figure 2. Ice from 17inch Disconnects

Video Camera OTV171: APU Exhaust Flame

Orbiter +Z APU vent exhaust visible at base of vertical stabilizer. Glowing APU exhaust gas/flame appears at periodic intervals of approximately 0.6 seconds starting at 336:03:05:32.721 UTC.

Recent missions (STS-92, STS-103, STS-106, STS-99, STS-101, STS-93, and STS-96) were reviewed for similar occurrences, but none were noted. JSC Image Analysis has reported that these flames appear similar to Orbiter flames typically seen during roll-out on night landings.

This observation was listed on the STS-97 Consolidated Film/Video Report.

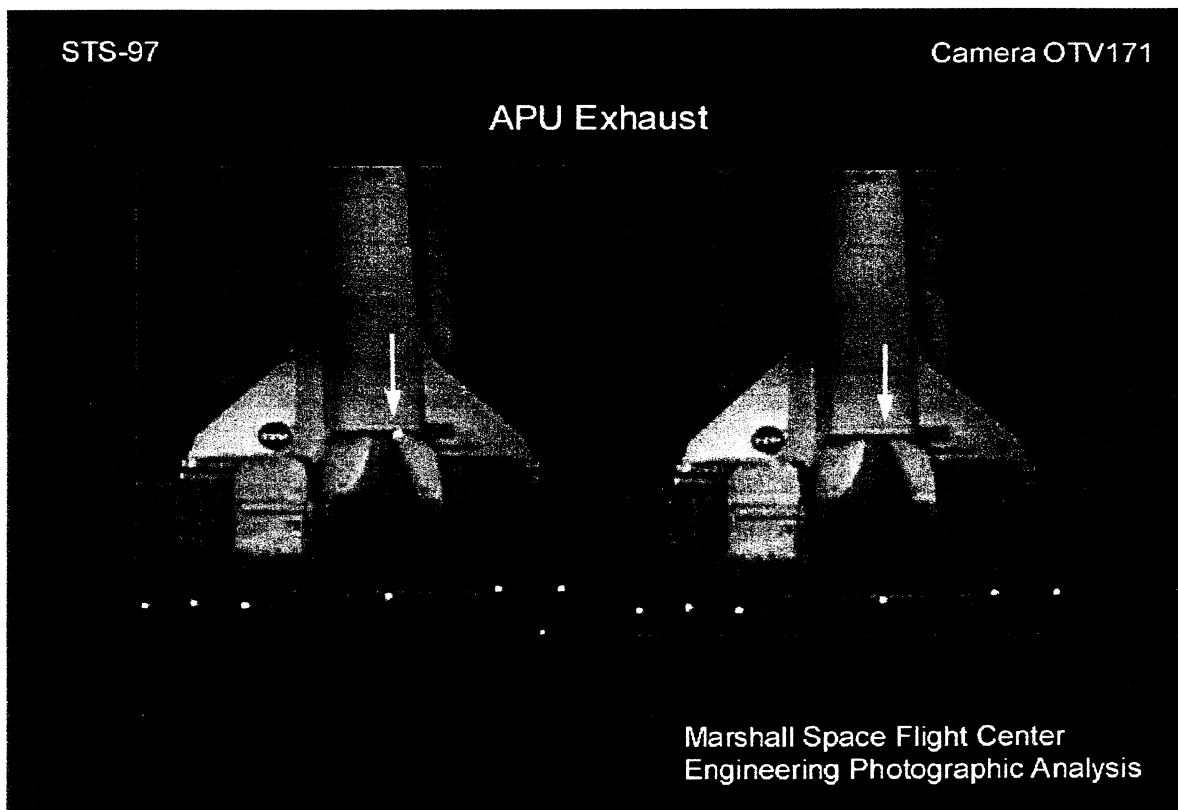


Figure 3. Top View: APU Exhaust Flame at Lift-off

Video Camera TV7B: APU Exhaust Flame

Figure 4 is a side view of the Orbiter on the launch pad prior to lift-off that illustrates the extent of the APU exhaust flame.

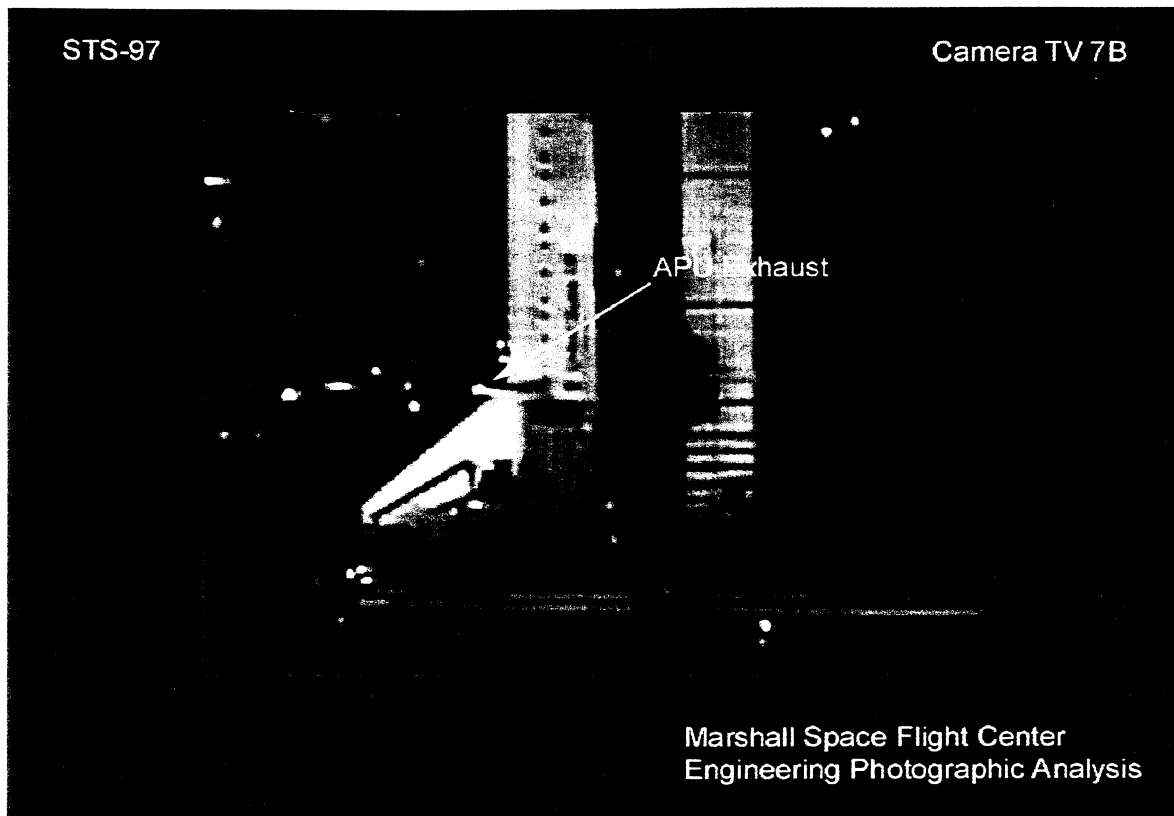


Figure 4. Side View: APU Exhaust Flame Prior to Lift-off

Video Camera TV4B: Pad Debris

The enhanced contrast area in Figure 5 illustrates typical pad debris. The debris in this image was noted to be moving away from the vehicle.

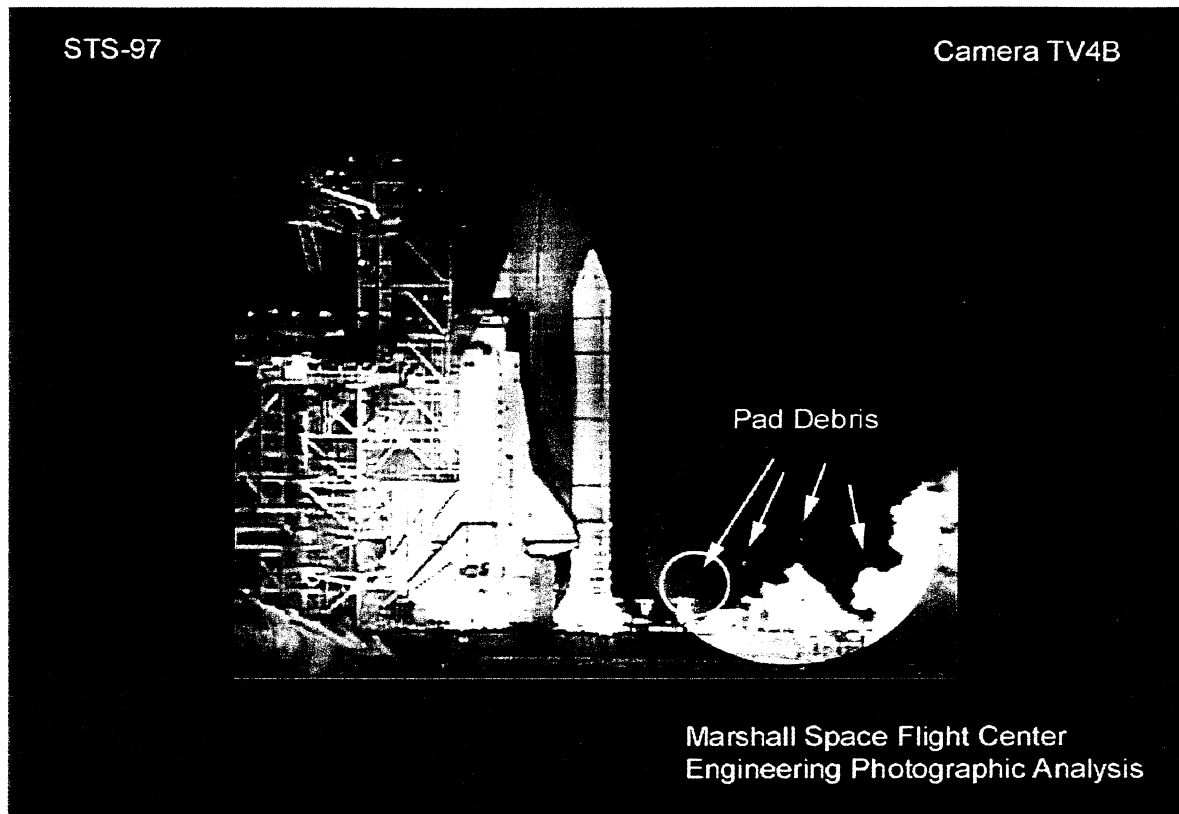


Figure 5. Pad Debris at Lift-off

Video Camera ET207: Dark Colored Debris

Pieces of dark-colored debris were observed near aft dome during roll maneuver. The source of the particles was not determined, but they did not appear to come from the region on the aft dome near the manhole cover. Also, no apparent large area of missing foam that might be the source of the debris was observed on the visible acreage of the aft dome.

As the foam debris particles were observed to rotate in the recirculation region near the aft dome, the reflectance of the particles did not change and the observed color remained dark.

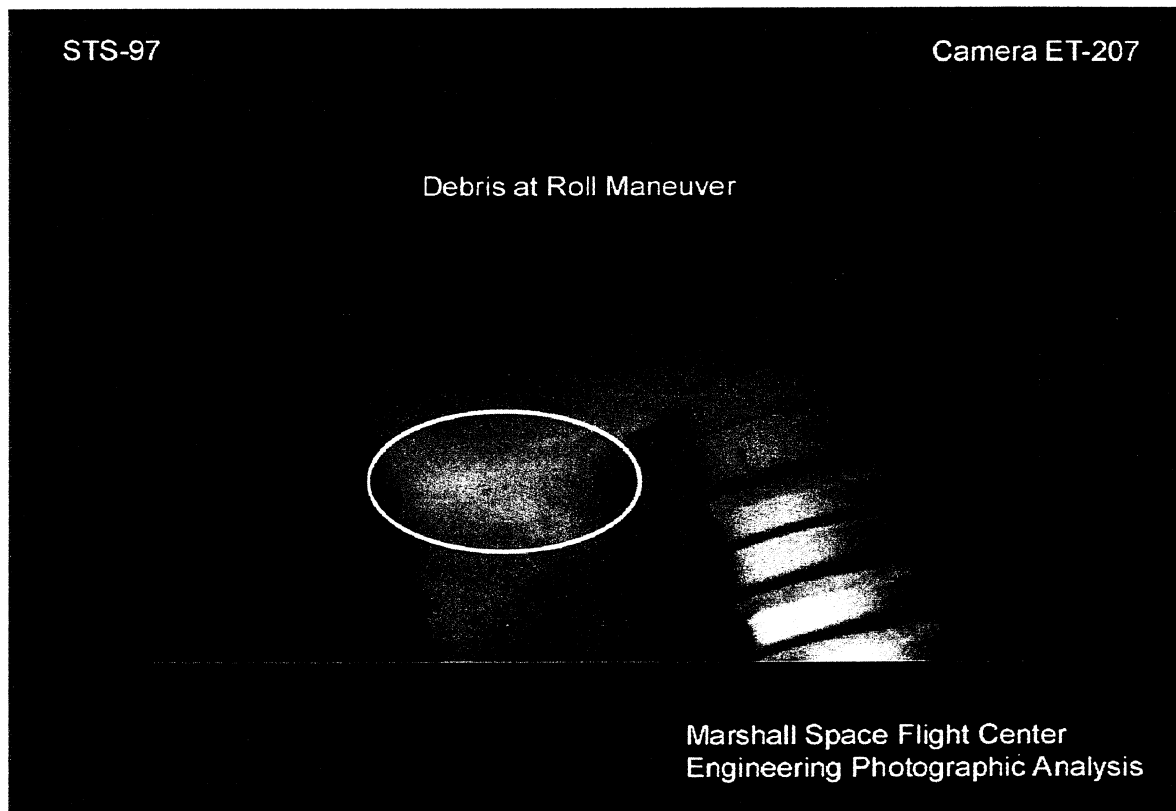


Figure 6. Dark Colored Debris near Aft Dome

Film Camera E222: Vapor from Vertical Stabilizer

Vapors, or possible impact debris, emanating from near the middle section of the aft edge of the vertical stabilizer were observed during ascent from approximately 336:03:06:45.7 UTC until 336:03:06:46.9 UTC.

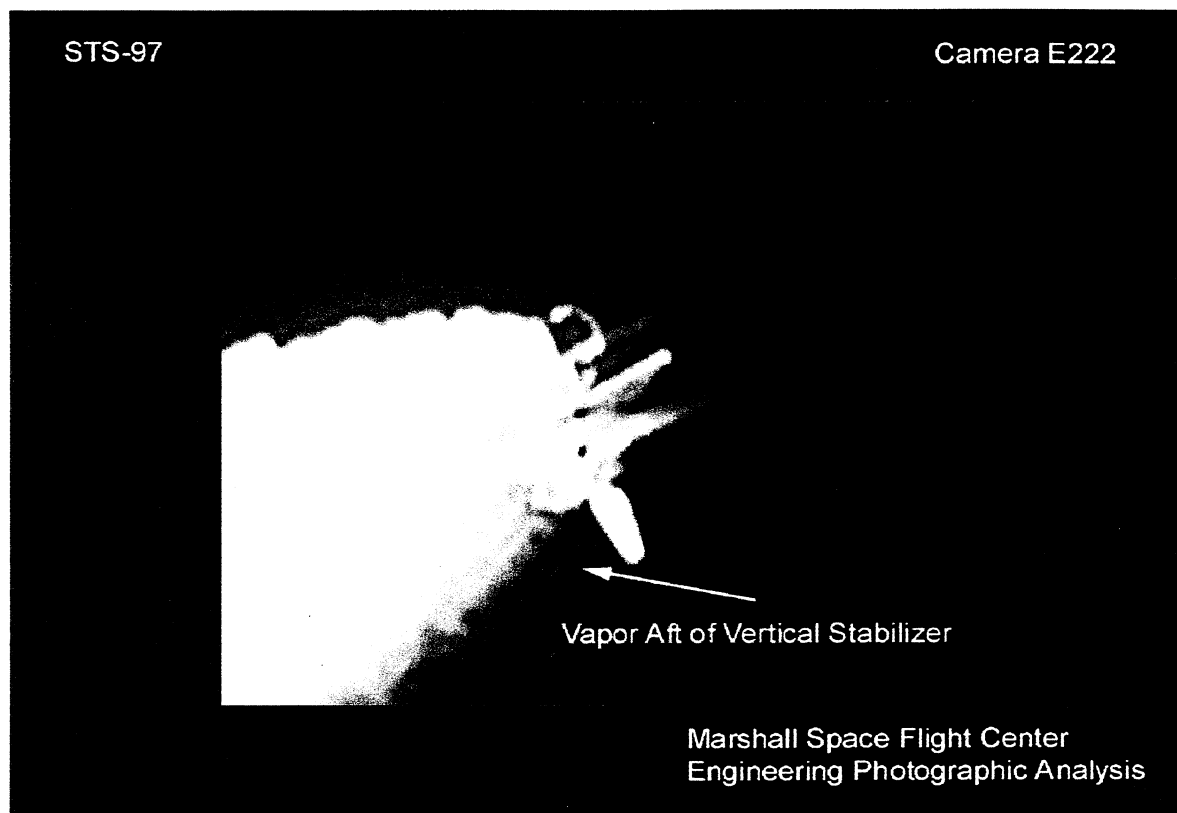


Figure 7. Vapor from Vertical Stabilizer

Video Camera TV4B: Debris from SRB Plumes

Typical debris ejected from SRB Plumes.

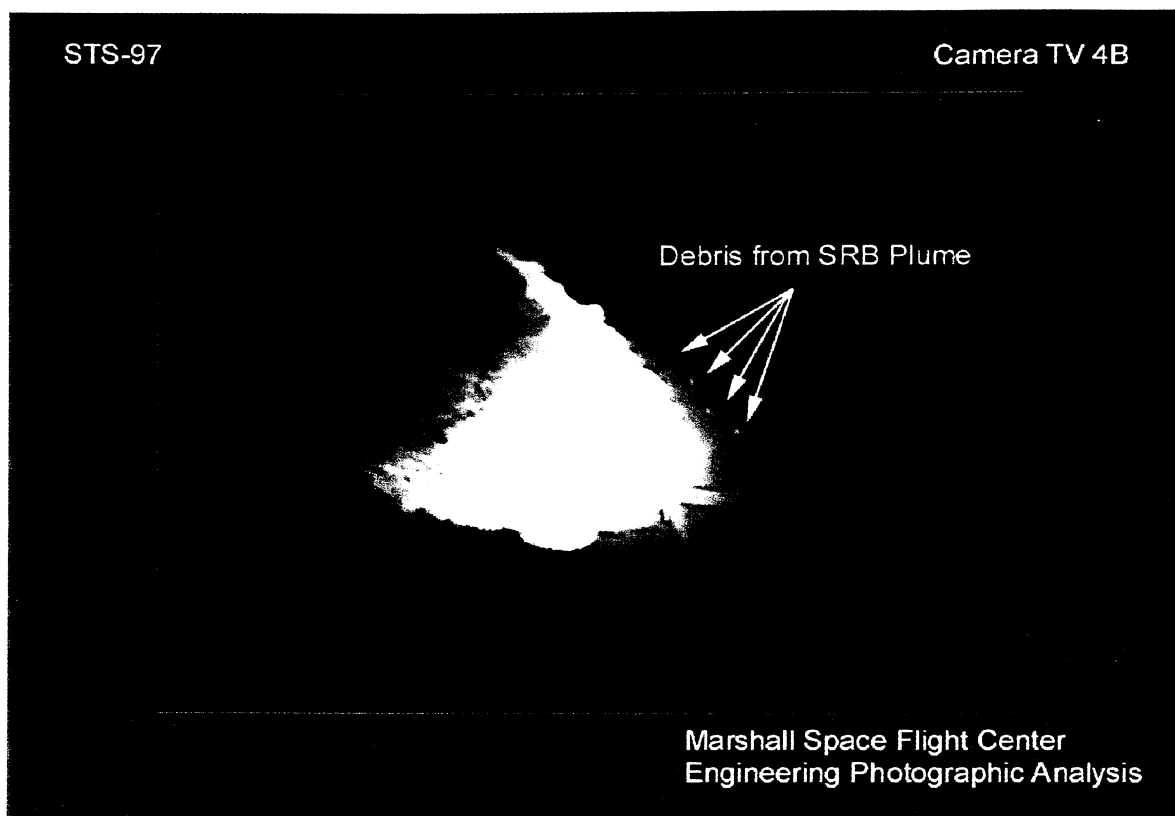


Figure 8. Debris from SRB Plumes

Astronaut Handheld 35mm Camera

Images from the Astronaut Handheld 35mm Camera are shown in Figure 9. No damage to the External Tank was observed. Due to the distance between the Orbiter and the ET, resolution is low and the level of detail is limited. Shadows also limit the visible ET acreage.

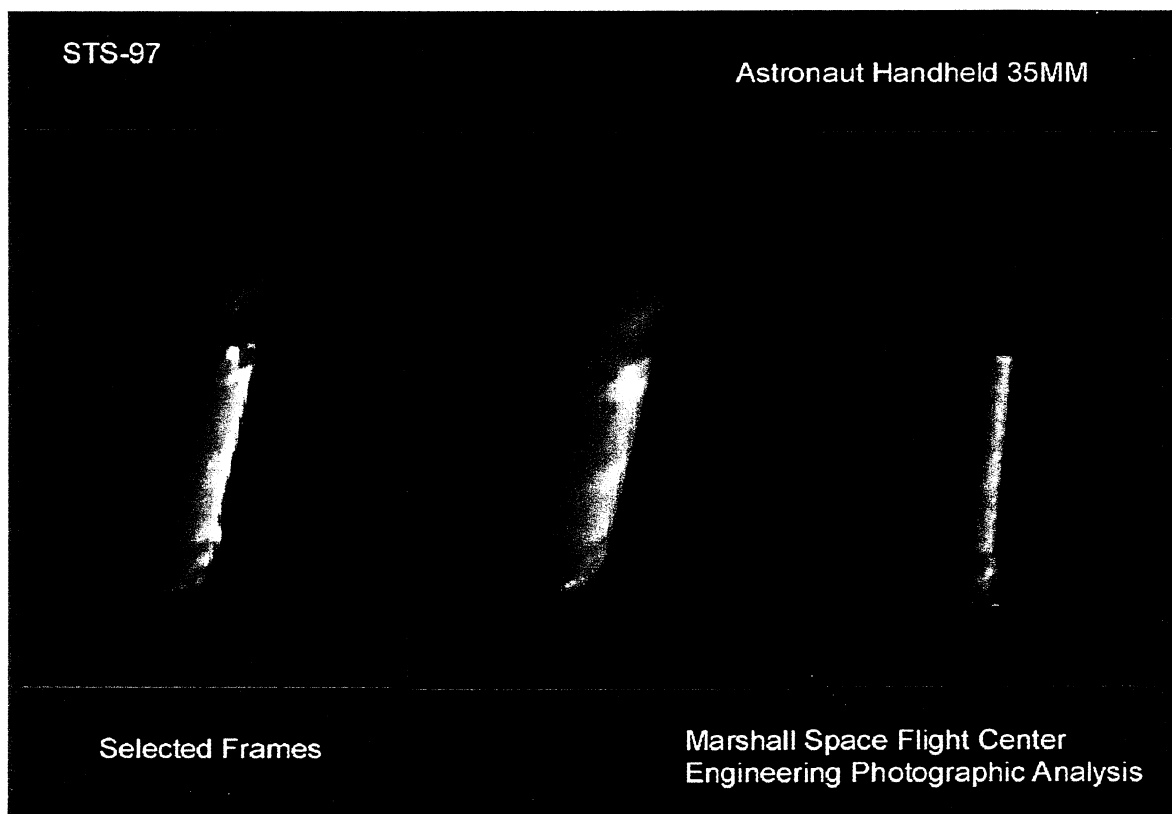


Figure 9. Views of the External Tank from the Astronaut Handheld Camera

Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras for flight STS-97 may also be found on the website.

Video Camera Assessments

- TV5 - Glowing debris particles ejected from SRB plume prior to separation.
- TV4B - Periodic APU exhaust gas at base of vertical stabilizer is visible before liftoff. Possible vapor or APU exhaust gas observed during ascent, aft of the vertical stabilizer at approximately 336:03:06:46 UTC. Pad debris observed, moving away from vehicle. Debris ejected from SRB during ascent before, during, and after separation. Image is overexposed as vehicle leaves the tower.
- TV7B - Typical pad debris noted rising and falling. Pulsed APU exhaust observed emanating from base of vertical stabilizer before liftoff. Free hydrogen burning noted above OMS Pods.
- ET207 - SRB separation: 336:03:08:04.863 UTC. Numerous pieces of dark-colored debris observed near aft dome during roll maneuver. Debris induced streaks observed in SSME plumes. Linear optical distortions observed. Glowing debris particles ejected from SRB plumes.
- ET212 - Glowing debris particles ejected from SRB plumes.
- TV21B - APU exhaust gas observed at base of vertical stabilizer. Free burning hydrogen observed.
- OTV109 - Typical ice/frost from LH2 disconnect.
- OTV149 - Camera OTV149 video was not available.
- OTV151 - Free hydrogen burning noted. Image becomes overexposed after engine start.
- OTV154 - Typical ice from 17-inch disconnect was noted. Also ice fell through the field of view from possibly two sources forward of the disconnect. One source near the Orbiter and the other near the right SRB.
- OTV160 - Close-up of right SRB segment. No debris observed.
- OTV163 - Typical ice/frost from LH2 disconnect.
- OTV171 - APU exhaust visible at base of vertical stabilizer. Glowing APU exhaust gas appears at periodic intervals of approximately 0.6 seconds starting at 336:03:05:32.721 UTC.

Film Camera Assessments

- E1 - Typical ice/frost from 17-inch disconnects.
- E2 - APU exhaust flame observed prior to and during liftoff. Free burning Hydrogen rises to height above OMS Pod.
- E3 - APU exhaust flame observed prior to liftoff.
- E4 - Debris ejected in near vertical trajectory from Right SRB Blast Hole during time interval 336:03:06:02.276-.537 UTC.

- E6 - Ice noted on SSME#2 eyelid. Ice falls through field of view from above LH2 disconnect.
- E8 - Pad debris noted rising and falling. SRB Holddown Post M2 PIC Firing Time at 336:03:06:00.994 UTC.
- E9 - SRB Holddown Post M1 PIC Firing time at 336:03:06:00.994 UTC. Stud hang-up observed. Holddown Post shoe was pulled up with the vehicle showing spherical bearing. The stud appeared to be fully extended until separation from SRB. The Holddown Post stud was observed to twang at separation from vehicle. After separation, the shoe returns to rest position and stud falls into HDP hole. Apparent minor debris was observed emanating from SRB foot hole on stud separation.
- E10 - Typical pad debris.
- E11 - SRB Holddown Post M7 PIC Firing Time observed at 336:03:06:00.996 UTC. Typical pad debris. Generally, this event is not observed because of the doghouse cover obscuring the view. This time, the flash from the PIC firing was observed and not the resulting smoke.
- E12 - SRB Holddown Post M5 PIC Firing time at 336:03:06:00.995 UTC. Typical pad debris.
- E13 - SRB Holddown Post M6 PIC Firing time at 336:03:06:00.994 UTC. Typical pad debris.
- E14 - Pad debris noted rising and falling.
- E15 - Pad debris noted rising and falling. Free Hydrogen burning observed.
- E16 - Pad debris noted rising and falling.
- E17 - Typical debris observed falling aft of vehicle. Free burning Hydrogen observed. Several small chips from base heat shield tiles observed.
- E18 - Free Hydrogen burning was observed. Ice was observed on SSME#2 eyelid. A noteworthy amount of ice from the 17 inch disconnects was observed falling through the field of view.
- E19 - Free burning Hydrogen observed. Mach Diamond formation in 3-2-1 order. Typical ice debris falling aft of the vehicle after liftoff. Very faint engine streaks noted on SSME#1 at times 336:03:06:01.475, 336:03:06:01.779, 336:03:06:02.046, and 336:03:06:02.258 UTC. A very faint engine streak was noted on SSME#2 at 336:03:06:02.258 UTC.
- E20 - Ice observed around SSME#2 eyelid. Typical debris falling aft of vehicle.
- E57 - Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to separation. RCS paper noted flowing from left side of vehicle over wing and past vertical stabilizer.
- E59 - Typical debris observed falling aft of vehicle. Forward RCS paper noted flowing past left wing of vehicle.
- E60 - Pad debris noted rising and falling. Typical debris observed falling aft of vehicle.
- E62 - Pad debris noted rising and falling. APU exhaust flame observed.
- E205 - Glowing debris particles ejected from SRB plume prior to, during and after separation. Tracking of vehicle begins late and was misframed. The vehicle was at the top of the frame, drifting in and out of the image.
- E31 - Typical ice/frost from 17-inch disconnects. Ice debris particle falls through field of view from forward of the LH2 disconnect.
- E33 - Ice debris from GUCP noted falling alongside vehicle.

- E34 - Typical debris observed falling aft of vehicle.
- E36 - Free Hydrogen burning observed. APU exhaust flames observed.
- E40 - Typical debris observed falling aft of vehicle.
- E52 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to separation. Pulsating APU exhaust visible at liftoff and after liftoff. Venting from water drain on vertical stabilizer observed just after liftoff.
- E54 - Typical debris observed falling aft of vehicle. Debris from forward left area of Orbiter observed flowing over left wing.
- E63 - Pulsating APU exhaust at base of vertical stabilizer observed. Film had very short run.
- E207 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks in SSME plume. Linear optical distortions noted. Flow recirculation noted. Typical body flap motion observed. Several occurrences of film handling marks were noted.
- E208 - Film not available. Camera had no run.
- E212 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks in SSME plume. Linear optical distortions noted.
- E220 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to separation. Pulsating APU exhaust observed prior to lift-off. Numerous film handling and processing marks. Orientation not as programmed. Consistent tracking of vehicle not achieved, vehicle is not imaged for substantial amount of time.
- E222 - Typical debris observed falling aft of vehicle. Two pieces of debris observed, prior to roll maneuver, forward of left wing that travel over the wing. Glowing debris particles ejected from SRB plume. Pulsating APU exhaust gas visible prior to, during and after liftoff. Vapors from near mid-aft area of vertical stabilizer were observed during ascent at 336:03:06:45.699 UTC and 336:03:06:46.899 UTC.
- E223 - Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Linear optical distortions noted. Glowing debris particles ejected from SRB plume. Vapor appears aft of vertical stabilizer after roll maneuver. Numerous film handling or processing marks observed.
- E224 - Typical debris observed falling aft of vehicle.

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REPORT DOCUMENTATION PAGE

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